The Conquest OF THE AIR

An Historical Survey

by

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PREFACE

THE aim of this small volume is to tell the story of man's conquest of the air in its historical setting. The facts and incidents that form the material of this story have been described more comprehensively and in greater detail in other works, and it is scarcely necessary for the author to acknowledge the obvious debt he owes to the research of previous historians of aeronautics. Here the endeavour has been to lay emphasis only on what was significant in the gradual evolution of successful flying machines.

The book is in no sense a technical treatise, and nothing has been included in it that might seem to lie outside the interests or ready understanding of the general reader. But the story of man's long effort to achieve mechanical flight cannot be thoroughly understood or appreciated unless it is considered in its relationship to the general advance in scientific knowledge and mechanical proficiency that has been in progress ever since the Renaissance. It was out of this accumulated heritage of scientific knowledge and mechanical proficiency that the aeroplane and the airship finally emerged at the beginning of the twentieth century.

No one can review the history of this struggle for the mastery of the air without recognizing the admirable courage and undaunted faith of the pioneers of flight. In the face of derision and indifference they were moved to attempt and accomplish deeds that may worthily rank with the more celebrated exploits of their fellow-adventurers on land and sea.

C. L. M. B.

Introduction :- By → O C Eancale

CONTENTS

LIST OF ILLUSTRATIONS

I

The Pre-Scientific Period

It was in the year 1783 that Pilâtre de Rozier accomplished in France the first flight in a balloon; and one hundred and twenty years later, in 1903, the Wright brothers in America flew a short distance in a heavier-than-air machine. By this latter date it may be said that the problem of human flight had been the subject of scientific study for nearly four hundred years, from the days of the Italian artist and scientist Leonardo da Vinci, who was born in 1452 and died in 1519. These four hundred years cover the period in which the problems of flight were realized, examined, grappled with, and finally solved; but they do not by any means circumscribe the period during which man has attempted to fly. Efforts at human flight extend backward to remote ages until they merge imperceptibly into the myths and poetical legends of antiquity. We cannot say who was the first man that essayed with great daring to fly, any more than we can tell who was the first adventurous spirit that tried to mount and ride a horse. We can only hope, in both cases, that they escaped without the serious injuries that their foolhardiness undoubtedly invited.

At the same time it should be clearly understood that these early dreams of flight and the occasional isolated attempts at actual achievement that are to be found in the ancient and medieval worlds differ essentially from the efforts made during the four centuries that preceded the first successful aeroplane. They occupy a picturesque, even a noble place in the story of the romance of flight, but they have no part whatever in the records of the science of aeronautics. It is perhaps necessary to mark this difference between the romance of flying and the science of aeronautics. It has been said that the histories of all civilized and even semi-civilized peoples provide evidence that in some way or another their imaginations were fired by the possibility of human flight; and that

throughout the ages men have desired to fly and have even tried to do so. This is perhaps true; but it is probably not an understatement to add that from the days of the early Greeks to the time of Leonardo da Vinci at the end of the fifteenth century the minds of men were no more occupied with thoughts of flying or the desire to fly than our minds to-day are concerned with the problem of communicating with the planet Mars. It is almost as true to say that the achievement of the one aim was as remote from practical accomplishment then as the other is to-day. No one as yet understands or can state the problem of interplanetary communication; similarly no one before the fifteenth century understood or could state the problems of human flight.

Once it is clearly realized that the stories and the deeds of these early flying men, whether legendary or historical, are of no significance in the annals of aeronautical science and did nothing to bring nearer to solution the real and practical problems of aerial navigation, one may safely give them a place in the story of the romance of flight.

The legends and folk tales of all peoples contain stories of flying men or supernatural beings; it is impossible, even if it might serve a useful purpose, to give an account of them all. The most famous and the one most frequently quoted is the Greek legend of Daedalus and his son Icarus. Daedalus and Icarus may have been real people, and they may even have made some attempt to fly; nevertheless, owing to the frequency with which their names are used in connexion with the earliest attempts at flight, it may be wise to insist that as we know them they are figures of pure legend and cannot be placed in any historical period or setting. Daedalus was, according to the story, an ingenious craftsman of an inventive turn of mind. He was credited with having originated a number of mechanical devices, including the use of sails in ships. Finding himself a prisoner on the island of Crete, he fashioned wings coated with wax, into which feathers were stuck. With the aid of these he and his son Icarus made good their escape, flying across the sea to

Italy. Later Icarus stole the wings and launched himself into the air. Unfortunately he was so ill advised as to fly too near the sun, with the result that the wax melted, and he fell headlong into the sea, 'henceforth Icarean'. That, briefly, is the legend of Daedalus and Icarus, and there are many others of a like nature.

From the region of mythology and fairy tale we come to accounts of attempted flight, which, though they can hardly be regarded as strictly historical, may yet with varying degrees of certainty claim to have a foundation on fact. Just within this category stands the story of one Bladud, ninth king of Britain, a dabbler in the black arts who broke his neck in an attempted flight—an inauspicious beginning to the story of aeronautics in this island. Then there is the record of Simon the Magician, who, in the time of the Emperor Nero, is said to have attempted to show his superiority to St. Paul by a flight which ended in failure. On the borderlands of history proper hovers the figure of the Saracen of Constantinople, who attempted to make an exhibition flight before the Eastern Emperor Comnenus in the hippodrome at Constantinople. His device appears to have been a primitive form of glider, but he fell and was fatally injured. When it is remembered that the Moors, or Saracens, were the only people of that time who may be said to have engaged in scientific study, there is just the chance that here was a genuine experimenter rather than a mere charlatan. It is interesting to note that in all instances of attempted flight during the period of the Dark Ages it was always assumed that the agency of evil was at the bottom of it. The orthodox view appears to have been something as follows: 'It is not necessarily impossible for human beings to fly, but it so happens that God has not vouchsafed them the knowledge of how to do it: hence it follows that any one who claims that he can fly must have sought the aid of the Devil. To attempt to fly is therefore sinful.' This attitude endured throughout the Middle Ages until the Renaissance and was characteristic of the mental attitude of medieval Christendom. Whether it was responsible for the comparative mental stagnation of this period, or,

as seems more likely, was merely one of its manifestations, need not be considered here.

In the thirteenth century the activities of a group of Franciscan friars in England marked the first stirrings of a new intellectual ferment. The most famous of these Franciscans, Friar Roger Bacon, betrayed a mental attitude differing fundamentally from the prevailing philosophy of his age. He was not content to accept the existing state of things as immutable, representing the unchanging will of God, but dared to look forward and regard knowledge as something capable of progress. With prophetic vision he saw the wonders that the future might hold.

'First, by the figurations of art', he wrote, 'there may be made instruments of navigation without men to rowe them, as great ships to brooke the sea, only with one man to steer them, and they shall sayle far more swiftly than if they were full of men; also chariots that shall move with unspeakable force without any living creature to stirre them. Likewise an instrument may be made to fly withall if one sits in the midst of the instrument, and doe turne an engine, by which the wings, being artifically composed, may beat the air after the manner of a flying bird. . . .'[1]

This single observation can hardly justify us in regarding Roger Bacon as a student of aeronautics, and the thought behind it was alien to the thought of the time. Nevertheless, it was a portent that the mental attitude of the Middle Ages would not last for ever. The plagues that ravaged Europe in the fourteenth century, together with the economic disorder that attended them, checked for a time the intellectual movements that appeared beneath the surface in the thirteenth century, but the forces of the human mind could not sleep much longer.

The demonology of the Middle Ages is filled with stories of wizards and witches who navigated the upper air with the assistance of tubs and broomsticks and similar devices unknown to modern aeronautical engineers, but there are also a few authenticated instances of men who, without laying claim to supernatural

[1] Quoted in Dr. Ivor B. Hart's *Makers of Science*.

Bladud reign'd 20. 863.

his *Bladud* had beene a Student in *Athens*, from thence he brought many

BAthe was by *Bladud* to perfection brought,
By Necromanticke Arts, to flye he ſought:
As from a Towre he thought to ſcale the Sky,
He brake his necke, becauſe he ſoar'd too high.

earned men, he built *Stamford*, a Colledge, I thinke, the first in *England*, ſtriuing to play the Fowle or the Foole, he brake his necke on the Temple of *Apollo* in *Troynouant*.

Bladud, mythical King of Britain

And firſt of all by the figuration of Art it ſelfe: There may bee made inſtruments of Nauigation without men to rowe in them: as huge Shippes to brooke the Sea, onely with one man to ſteere them, which ſhal ſaile farre more ſwiftly then if they were full of men. And Chariots that ſhall mooue with an vnſpeakeable force, without any liuing creature to ſtirre them: ſuch as the crooked Chariots are ſuppoſed to haue beene, wherein in olde time they vſed to fight, yea inſtruments to flie withall, ſo that one ſitting in the middle of the Inſtrument, and turning about an Engine, by which the winges being artificially compoſed may beate the ayre after the maner of a flying bird. Beſides, there

Friar Roger Bacon's prophecy of mechanical flight: thirteenth century

O P Gazzali
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powers, did definitely attempt to fly by natural means. Usually they constructed artificial wings or some inadequate form of glider and precipitated themselves into space from an eminence such as a tower or a cliff, usually with disastrous results to life or limb. Such an one was Oliver, the monk of Malmesbury, who attempted in 1065 to emulate the mythical performance of Daedalus. Later and overlapping in time the earliest scientific study of flight come similar instances, such as that of the mathematician Regiomontanus, who is said to have constructed a mechanical eagle which flew to meet the Emperor Charles V on his entry into Nuremberg, and Giovanni Battista Danti, who is credited by a later chronicler with having achieved successful glides over Lake Trasamene before he met with an accident in attempting to fly across the Piazza at Perugia. Another pioneer was John Damian, a physician at the Court of James IV of Scotland, who constructed a pair of wings and 'took in hand' to fly from the castle walls at Stirling, but fell and 'brake his thighbone'. Such men were bold pioneers and for daring their names may rank among the later and more successful heroes of the air. Their achievements, however, whether derided by their contemporaries or exaggerated by later chroniclers were barren of fruitful result. They left no legacy to their successors, unless it were the inspiration of their courageous ambition. It may truthfully be said that when the fifteenth century ended man was no nearer to solving the problem of flight than he had been at the dawn of history.

II

The Pioneers of Aeronautical Science

Those centuries that we call the Middle Ages, so strangely fascinating and attractive to the modern mind, end with the Renaissance that spread westward across Europe in the fifteenth and sixteenth centuries. They were ages of faith, almost of fatalism; men's minds were turned backwards to a vanished

golden age or upwards to the blessings of a life not of this world. The saints and thinkers of medieval Europe had faith in God, but very little in man, least of all in his intellect. Knowledge they held to be a dangerous thing; God, through Holy Church, would give men all the knowledge they needed for the health of their souls, and beyond that what else mattered? Whether or not anything else matters is a philosophical question that we need not consider here; it is enough to say that this attitude of mind did not lead men forward to those achievements for which self-confidence, careful research, and an appreciation of exact knowledge are essential.

The Renaissance, which for good or ill shattered this secure medieval world of faith and set men off on the feverish quest for knowledge that they still pursue, marked the beginning of the modern age. Its essential characteristic was an intense intellectual and imaginative energy which made itself felt in every branch of human activity. Men were no longer content to believe and live by precept; they wanted to explore the world and its newly glimpsed prospects for themselves, to inquire, to test by actual experience and experiment. They began to have faith in themselves and in the powers of the human mind; to develop what in its broadest sense we may call the *scientific method* of thinking.

It was this new attitude of mind that produced, ultimately, the epoch-making inventions of the eighteenth, nineteenth, and twentieth centuries; that gave the world, among other things, the aeroplane. The aeroplane was a product of human faith, but faith of a different sort from that which animated the medieval theologians and saints.

Leonardo da Vinci, chiefly famous as an artist, exhibited the manifold intellectual interests that characterized the men of the Renaissance period, and calling himself a philosopher studied science in its many branches. He was the first man known to have considered the problems of flight from the scientific point of view. He sought exact knowledge of the subject and studied the flight of birds.

'A bird', he wrote, 'is an instrument working in accordance with mathematical law, which instrument it is within the capacity of man to reproduce. . . .'[1]

It is wellnigh impossible to exaggerate the importance of this seemingly simple statement. At one bound it lifts the problem of flight from the regions of fantastic romance and medieval magic to the plane of natural science and common sense. 'A bird is an instrument working in accordance with mathematical law.' Realization of this essential fact was the primary contribution of the Renaissance to aeronautical science. Here was solid matter upon which to work; the road along which progress could be made was plainly indicated. Men must first make themselves acquainted with the mathematical laws that govern the flight of a body through the air and must then devise, in accordance with these laws, a mechanism capable of supporting a human being. Centuries of patient study, research and experiment, of small successes and disheartening failures were necessary before this feat could be accomplished. Nevertheless it is hardly too much to say that once the elementary fact of da Vinci's statement was understood the evolution of a successful flying-machine was ultimately inevitable.

It must not be assumed from the above that Leonardo da Vinci was in any sense the founder or leader of a school of thought in aeronautical science. On the contrary, his work received scant attention in his own day and was soon forgotten: only in comparatively recent times has its full value been realized. Its significance lies in the fact that the time was at hand when men could approach and comprehend the problems of flight in the way da Vinci had done. His direct influence was slight: the influence of his scientific method of thought, the leaven, as we may say, of the Renaissance spirit that was steadily informing the minds of men, made the eventual solution of the problem possible.

A brief account of da Vinci's treatment of the problem of aeronautics will be sufficient to show how far he stood in advance of

[1] *A Treatise on the Flight of Birds*, L. da Vinci.

any of his predecessors, and, indeed, of many who came after him. His place is rather among the men of the nineteenth century than with the ambitious but not very helpful enthusiasts of the sixteenth and seventeenth centuries.

He began with the scientifically sound but somewhat deceptive principle of studying the flight of birds. He held that while men might never be able to attain the extreme skill in flight that birds possess owing to their specially favourable structure, still they could probably learn from them the primary secrets of flight and be able to imitate them in a simple fashion. He saw that we should study the 'science of the winds' in order to arrive at a 'knowledge of the winged creatures in the air and in the wind'. He began to understand the importance of the resistance which the air will offer to any object and so was led to devise a parachute. He went on to deal with the question of the centre of gravity in birds, discussed what he called 'the centre of resistance', and even touched on the important subject later known as 'stream lining'. He experimented with a mechanical wing, but does not appear to have learned very much as a result. He also invented a model 'helicopter' (a device that will be discussed later) which flew with some success.

Da Vinci undoubtedly learned much about the principles which govern the flight of birds, but not unnaturally he was deceived into paying too much attention to the assistance that birds derive in flight from the beating of their wings against the air. Birds propel themselves by means of their wings, but it was later to be shown that the attempt to produce this function of the wing was not the right way for men to fly. The wings of birds, as well as being natural propellers are also natural gliders—that is to say, when outspread without motion they offer a sufficient resistance to the air to support the bird in flight. This was the great lesson that the birds had to teach the human flyer. How it was learned, slowly and gradually and at the cost of many lives, will be seen in due course.

Two men only appear to have been directly led to experiments in flight by the work of da Vinci. One was Paoli Guidotti, an artist

of Lucca, who constructed a pair of wings on a framework of whalebone and made gliding flights which apparently met with some success. According to the story, however, he ended one of his ventures on a housetop and broke his leg, a misadventure that appears to have cooled his enthusiasm, for we hear no more of him as a flying man.

The second disciple of da Vinci was an architect named Veranzio, who lived at Venice. He followed up the idea of the parachute and, it would seem, improved on da Vinci's plan. He devised 'a sort of square sail extended by four rods of equal size and having four cords attached at the corners'. By means of this parachute he made safe descents from the tops of buildings. It is not quite clear whether he inquired scientifically into the problem of the resistance offered by the air to a given surface. He appears to have confined his actual practice to parachute descents, and he relinquished his experiments about 1618.

During the seventeenth century little was actually done to bring the problem of flying nearer a practical solution, but the subject attracted the attention of a number of men of science who freely discussed its possibilities. From the latter half of the seventeenth century onwards it may safely be asserted that the study of aeronautics was always engaging some one's attention. Men were at least beginning to understand some of the difficulties of the task that confronted them; the foundations of the science were slowly laid, and instead of isolated attempts starting, as it were, from nothing, students and experimenters found themselves able to build upon the knowledge gained by their predecessors, to correct the errors into which they might have fallen, and little by little to add to a growing body of more or less exact information.

In England Charles II granted a charter for the formation of the Royal Society in 1662. This institution, which had originated in private meetings of 'divers worthy persons inquisitive into natural philosophy', was one of the manifestations of that intense scientific activity which developed at this period. This was the age of

Newton and Leibnitz and other famous pioneers, and it marks the final vigorous workings of the Scientific Renaissance that were soon to bear fruit in the mechanical inventions of the eighteenth and nineteenth centuries, and by supplying the motive power to the Industrial Revolution, to change fundamentally the lives of the people of Europe, and eventually, it would seem, of the whole world. Men were just beginning to realize the illimitable possibilities of science, to realize them vividly and boldly as, vaguely and almost fearfully, old Friar Roger Bacon had envisaged them in the twilight of the Middle Ages. Nothing seemed to them impossible; no wild surmise was too daring. It is small wonder that sober level-headed folk regarded their prophecies as the grotesque romancing of men who had let their enthusiasm outrun their common sense. And if we are ever tempted to think the same when we read of them discussing the possibilities of 'a voyage to the southern unknown tracts, yea, possibly to the moon' or 'the restoration of grey hairs to juvenility and renewing the exhausted marrow', we may well pause for a moment before we allow ourselves to smile. No less preposterous to their contemporaries seemed their prediction that men would 'fly into remote regions'. In the world of science the incredible vision of to-day is the sober reality of to-morrow.

One of the prime movers in the young Royal Society was Bishop Wilkins, who had already contemplated the problem of human flight and discoursed on the subject in scientific treatises. Francis Bacon at a somewhat earlier date had made one or two references, not very helpful, to the possibilities of flight, but it was left to Wilkins to bring the subject before men's minds as a reasonable proposition.

In 1648 Wilkins had published a work entitled *Mathematical Magic*, in the second part of which he discusses various novel suggestions by which artificial locomotion might be achieved. Two chapters (VII and VIII) deal with the art of flying.

He begins by declaring that there are four ways by which it

might be possible to achieve flight. First of all there is the manner successfully practised by spirits and angels, but this line of approach he regards as outside the field of scientific inquiry. Secondly, he thinks that men might perhaps learn to harness the birds of the air. Thirdly, men might devise wings after the manner of Daedalus, or they might build a flying-chariot.

Wilkins then proceeds to discuss the practical possibilities of these two latter plans, without disguising the many serious difficulties that must be overcome. He remarks on the comparative weakness of the arms of man, and goes on to say, with truth and not a little insight, that in any case constant practice would be necessary before a man could hope to manipulate wings with success. (This fact was often not sufficiently realized by later would-be flying men.)

The flying-chariot, large enough to carry a number of persons, he considers the most practicable suggestion. He goes at once to the main difficulty: how is a substance so unresisting as the air to support the inevitably heavy weight of such a contrivance? Furthermore, could it be adequately propelled by human effort, even that of several people combined or working, so to say, in shifts? He is not dismayed by these severe difficulties. Soaring birds, he says, can make considerable progress through the air with a minimum of exertion once they have attained a sufficient altitude, and from this argues rightly that once the chariot can be made to rise from the ground it will not need a very great amount of energy to keep it moving through the air. Long practice and patient experiments will be necessary before the correct proportions of the machine can be discovered, but that must not be allowed to discourage man from the attempt. Success can only be attained slowly and by degrees. Further, he asserts bravely and in the true scientific spirit, that we must not despair of discovering some other and greater motive power if human muscles prove inadequate to the task imposed upon them.

Wilkins also expounded briefly the theory of lighter-than-air flight, but gave no hint of how it might actually be achieved. In

the main he appears to have held that the best way to tackle the problem was to imitate nature (i.e. the flight of birds) as closely as possible—a conception partly, but not wholly sound. Many false speculations, not unnaturally, occupied his mind; he kept returning, for instance, to the pleasing idea that the force of gravity would cease to operate at a certain altitude, thus showing that Newton's intuitive vision of 'gravity extending to the orb of the moon' had not been vouchsafed to him. It may be fairly urged against him that his work lacked precision; that it gave no good and solid 'data' to the man who wished to construct a pair of wings or a flying-chariot. He did not get down to what we may call technical details. Admitting this, it would be unfair to belittle the importance of Wilkins. If he did nothing else, he roused widespread interest in the problem of flight, and by his scientific zeal and sincerity and faith did much to convince people that the problem was one capable of solution. His was the voice of science proclaiming that the seemingly impossible is in reality not impossible, that only lack of knowledge holds men back from achievements and triumphs of which as yet they scarcely dream.

In addition to the interest awakened in scientific circles by Wilkins's publication, there is no doubt that he often personally discussed the subject of flight with his friends and colleagues of the young Royal Society, so that for a time at least it may almost be said to have been a familiar subject for 'philosophic' speculation. We find that Robert Hooke, a friend of Wilkins and later a secretary of the Royal Society, devotes his attention to the problem. Hooke was a scientist of considerable ability and achievement, and his work on flying takes but a minor place in his activities, but it is at least interesting in so far that it is the 'earliest, albeit incomplete and tentative efforts of an English scientist engaged in laboratory experiments on flight'.[1]

While still a schoolboy Hooke is said to have 'invented (perhaps "imagined" would be a fairer term) thirty several ways of flying'.

[1] Hodgson, *History of Aeronautics in Great Britain.*

In later life he constructed model flying-machines, with some of which he had some success, but they do not appear to have led to any definite results. When Secretary of the Royal Society he published papers in which recent scientific inventions were discussed, and referred to some experiments in flying. Among these he mentions the name of Besnier, a smith of Sable, who is said to have achieved flight by the aid of a contrivance of gliders. If the descriptions of Besnier's invention that have come down to us are at all accurate, we may assume that Hooke was justified in concluding that it was of not much practical account.

We have now reached the stage when the instances of men devoting their attention to the problem of flight, either through experiments or in theory, become so numerous that no significant purpose can be served by making individual mention of them all. It is not the aim of this book to offer a full and detailed history of early attempts at flight ; that has been done already in larger works of a different scope. Here we seek only to trace the steps by which successful flight was ultimately achieved, and must limit our examples and instances to those which are definitely significant in the story of the slow but progressive advance of aeronautical knowledge.

Two other names should be mentioned before this present chapter closes. They are those of Francesco Lana and Giovanni Alfonso Borelli. The work of Lana, who may perhaps be described as 'the grandfather of the balloon', may be more properly discussed in the chapter dealing with the development of lighter-than-air flight: Borelli, however, comes in aptly at this point, as his work marks the end of the first stage of progress in aeronautical science.

He was born in 1608, and is known to have been in communication with members of the Royal Society ; his great work on the subject of flight, a section entitled 'De Volatu' of his treatise on the movements of animals (*De Motu Animalium*), was published in 1680, after his death. Borelli examined, critically and exhaustively, the methods of bird flight, the structure of their wings and the relation

between their 'wing-power' and the weight of their bodies. In the main, his observations were shrewd and accurate, though like da Vinci before him (with whose work, now forgotten, he was not acquainted) and others, he fell into the error of ascribing too much importance to the downward beat of a bird's wing as the means employed to maintain its body in the air. His calculation that the motive force in a bird's wing is 10,000 times greater than the resistance of its total weight is also a greatly exaggerated estimate, but the deductions he made from it are none the less true, or at least have never yet been demonstrated to be false. His conclusion, backed by convincing scientific argument, was that it is anatomically impossible for man to support himself in the air by his own muscular strength. Here is his own statement:

'When, therefore, it is asked whether men may be able to fly by their own strength, it must be seen whether the motive power of the pectoral muscles (the strength of which is indicated and measured by their size) is proportionately great, as it is evident that it must exceed the resistance of the weight of the whole human body 10,000 times (this, as we have said, is an inaccurate figure, but not sufficiently inaccurate to falsify the argument), together with the weight of enormous wings which should be attached to the arms. And it is clear that the motive power of the pectoral muscles in men is much less than is necessary for flight, for in birds the bulk and weight of the muscles for flapping the wings are not less than a sixth part of the entire weight of his body; so also the arms, by flapping with the wings attached, should be able to exert a power 10,000 times greater than the weight of the human body itself. But they are far below such excess, for the aforesaid pectoral muscles do not equal a hundredth part of the entire weight of a man. Wherefore either the strength of the muscles ought to be increased or the weight of the human body must be decreased, so that the same proportion obtains in it as exists in birds. Hence it is deducted that the Icarian invention is entirely mythical because impossible, for it is not possible either to increase a man's pectoral muscles or to diminish the weight of the human body; and whatever apparatus is used, although it is possible to increase the momentum, the velocity or the power employed can never equal the resistance; and therefore wing

flapping by the contraction of muscles cannot give out enough power to carry up the heavy body of a man.' [1]

This indeed was a sad blow to those enthusiasts who, inspired by the prophetic words of Wilkins and others, were already allowing themselves to dream of aerial voyages to the moon. It is generally said that Borelli's contributions to aeronautical science were of a negative character and that he retarded rather than encouraged the study of it ; and although he made many sound and useful observations on such matters as the shape and formation of birds' wings, their method of decreasing speed when about to land, and the resisting properties or elasticity of the atmosphere, this conclusion must be accepted as a true one. Nevertheless he advanced the science if only by showing one of the ways by which man could *not* achieve flight. His work may best be regarded as complementary, rather than opposed to that of Wilkins : he demonstrated that one of the ways by which men might hope to fly was a blind alley, and since at the moment men could not conceive of any other direction that they might profitably explore, scientists generally came to the conclusion that human flight was impracticable. Nearly a hundred years later the advent of the steam-engine opened up new possibilities ; the prohibitions expounded in Borelli's arguments were no longer the insuperable obstacles they had seemed to be at the end of the seventeenth century. A new era was opened in the history of aeronautics.

It may be as well to summarize briefly the progress made by the beginning of the eighteenth century. Leonardo da Vinci, the spokesman of the Renaissance, had declared that flying was a mathematical and mechanical problem, not a mystery or an occult art, and therefore within the field of human endeavour, a matter to be tackled not by magic spells but by the intellect. Bishop Wilkins, whom we may take as representing the enthusiastic body of seventeenth-century scientists, was the prophet boldly foretelling the ultimate accom-

[1] Quoted in *A History of Aeronautics*, by E. C. Vivian and W. Lockwood Marsh.

plishment of flight. Flying devices and flying-machines became a familiar matter for speculation. There is little practical achievement or advance, but more and more minds become interested in the subject. It is felt that success will certainly be reached eventually, and probably as the result of the study and imitation of bird flight. Then comes Borelli, who proves to the satisfaction of scientists that men will never be able to fly as the birds fly; that the muscular power of man is demonstrably insufficient to raise and maintain the weight of his body in the air.

From this point interest in the subject flags until the appearance of the steam-engine as a practical motive force about the end of the eighteenth century. Until then Borelli's objection appears insuperable, as no one conceives of any form of power to be used in flight other than natural muscular energy. But before the day of the steam-engine another and entirely different principle of flight had captured the attention of Europe. This was the principle of the lighter-than-air flying-machine, which with surprising suddenness gave birth to the balloon.

III

Origin and Development of the Non-Dirigible Balloon

§ 1

The story of the balloon is easier to tell than the story of the aeroplane, just as the theory of the lighter-than-air flying-machine is simpler than that underlying heavier-than-air flight—or, at least, once understood it can be much more readily realized in actual practice. The number of unsuccessful aeroplanes that were constructed, even after the main principle of the plane was understood, is legion: yet so far as we know the first man who actually experimented with a balloon immediately achieved a striking measure of success. It may be said that the balloon (using this

term to denote a non-dirigible lighter-than-air craft, as distinct from the airship or dirigible balloon) shot suddenly up before the eyes of an unsuspecting and astonished world, causing an immense sensation of wonder, and arousing wild enthusiasm. The aeroplane, on the contrary, was an invention of gradual and laborious growth that progressed slowly through repeated failures to small and unspectacular successes. Even when heavier-than-air flight was an accomplished reality it at first made little impression upon the scepticism of the times, and had a hard struggle against an official and popular indifference that refused to grasp the significance of its achievement. Nevertheless, the successes of the non-dirigible, or 'free' balloon, though startling, were limited: the balloonists encroached upon the air, but did not conquer it. The immense airships of to-day, though they cannot deny the balloon to be their first parent, are not its direct and natural development in the sense that the most perfect modern aeroplane is the natural and, one may say, the inevitable outcome of the machine with which the Wrights made their first flight. The airship has essential characteristics that did not exist, even in embryo, in the balloon.

The principle upon which lighter-than-air flight depends was first enunciated by the Greek scientist Archimedes (died 212 B.C.), in his statement of the laws governing the flotation of bodies in liquids and gases. 'Every body' (said Archimedes) 'which is immersed in a fluid is acted upon by an upward force exactly equal to the weight of the fluid which is displaced by the immersed body.'

A body, therefore, will rest in any position if immersed in a fluid of equal specific gravity; if the body has greater specific gravity than the fluid it will sink; on the other hand if it has a less specific gravity it will float. Since Archimedes' law can be applied to all gases, including the atmosphere, it follows that a balloon will rise in the air if its total dead weight is less than that of the air which it displaces.

This law had long been known to scientists, and as early as the fourteenth century a certain scholar, Albert of Saxony, had

declared that in theory the air might be considered navigable on this principle. In the seventeenth century Francesco di Mendoza, Gaspard Schott, and Bishop Wilkins had made passing references to this law in its relation to the possibilities of aerial navigation, but it was left to Francesco Lana, a Jesuit living in Rome, to embody the theory in an actual and detailed plan for achieving flight. Lana had aimed at producing an encyclopaedic work of vast proportions which should contain the sum of the scientific knowledge of his day. Two volumes of this ambitious work were produced before his death in 1687, but he had already sketched an outline of the complete work, which contains two chapters describing a proposed aerial ship.

His idea was simple, and sound in principle. The body of the ship was to be attached to four globes, each measuring about 25 ft. in diameter, to be made of thin sheets of copper metal. All the air was then to be extracted from the globes, thereby causing them to become lighter than the atmosphere, and enabling them to rise and support the weight of the ship and its crew in the air. Propulsion and direction were to be obtained by sails and oars.

This device is impracticable for two outstanding reasons. Firstly, the copper globes, containing only a vacuum, could never withstand the pressure of the outside atmosphere : Lana himself foresaw this danger, and sought to evade it by arguing that as the pressure would be equal at all points it would tend rather to strengthen their power of resistance. Secondly, it was later to be demonstrated that sails are unavailing to propel or direct a light body floating freely in the wind, and oars manipulated only by muscular energy are totally inadequate for any such purposes. Fettered by his vows of poverty, Lana was prevented from the attempt to construct a ship in accordance with his ingenious design, and so was never able to put it to the test. It remained a theoretical conception, and in aeronautics more than in any other science the theories of the student must needs be constantly checked and revised by the results of their practical application.

Superficially it may be said that Lana did nothing more decisive than to design a flying-ship that could never have flown—as was demonstrated nearly two hundred years later by an experiment with copper globes such as he had designed. Even in his own age scientists such as Hooke and Borelli could point out its theoretical weakness. Still, Lana's flying-ship was wrong only in detail; the fundamental principle upon which it was based was sound—was, indeed, the principle of the balloon and the dirigible airship.

Like the work of Bishop Wilkins, however, Lana's proposal was chiefly important for the interest it aroused. Scientific men might point out its defects and declare that such a contrivance could never achieve flight: they could not deny the essential truth upon which it was founded. The possibilities of a flying-machine on the lighter-than-air principle were widely discussed and no Borelli could arise in this case to demonstrate the basic impossibility of the idea, whatever holes he might pick in Lana's actual design. For the moment further progress was held up: just as the heavier-than-air machine waited upon the discovery of a motive power, so the balloon lacked as yet a sufficient lifting force that should fulfil the necessary condition of making it lighter than air. The balloon, however, had not long to wait.

It is in these days very interesting, and perhaps a little discouraging, to read what Lana himself held to be the chief obstacle in the way of success.

'I do not foresee', he says, 'any other difficulties that could prevail against this invention, save one only, which to me seems the greatest of them all, and that is that God would never surely allow such a machine to be successful, since it would create many disturbances in the civil and political governments of mankind. Where is the man who can fail to see that no city would be proof against surprise, when the ship could at any time be steered over its squares, or even over the courtyards of dwelling-houses, and brought to earth for the landing of its crew? . . . Iron weights could be hurled to wreck ships at sea, or they could be set on fire by fireballs and bombs; nor ships alone, but houses, fortresses and cities could be thus

destroyed, with the certainty that the airship could come to no harm as the missiles could be hurled from a vast height.'

The last European war has shown that Lana's theological speculations were no more reliable than his belief in the resisting powers of copper globes; and mankind has learned that it must not lightly rely on a divine intervention to prevent it from encompassing its own destruction.

We may now pass from the theory or basic principle of lighter-than-air flight, generally admitted and understood by scientists in the early years of the eighteenth century, to the evolution of the means which enabled it to be applied in practice, and thus produced the balloon. Further progress depended upon a knowledge of the constituents that form the common atmosphere and the properties of 'inflammable air', or, as we should say, gases.[1] This knowledge was gradually obtained during the middle period of the eighteenth century as the result of the work of such famous chemists as Cavendish, Black, Priestley, Cavallo and others working in this country and on the Continent.

During the latter part of the seventeenth century scientists like Robert Boyle and Hooke were experimenting and making discoveries about the weight and 'elasticity' of the atmosphere and the effect of heat in causing air to expand. It was Henry Cavendish, however, who about the middle of the eighteenth century effectively demonstrated the nature and property of 'inflammable air', or, as it was eventually termed, hydrogen. Cavendish was born abroad in 1731, studied at Cambridge, and afterwards devoted the greater part of his life to scientific and particularly to chemical research. In 1766 'Three Papers, Containing Experiments on Factitious Air' were read before the Royal Society, in which he demonstrated the

[1] It might perhaps be argued that the Montgolfiers' 'hot air' balloon did not really depend on such scientific knowledge and could have been invented at almost any period. The important point nevertheless remains, that it was *not* invented, or even thought of, until the knowledge diffused by the eighteenth-century chemists suggested the idea to the Montgolfiers.

relative densities of hydrogen and air. Although his figures were afterwards shown to be slightly inaccurate, the value of his work was not thereby seriously impaired. Though Cavendish did not 'discover' the existence of 'inflammable air', he defined and expounded its nature and properties.

Here, then, in hydrogen gas, was that lifting force of which Lana had lacked knowledge, and which he had thought to supply by his device of copper globes containing a vacuum. Once the properties of hydrogen were understood it did not require outstanding originality or genius to think of applying it to the problems of 'aerostation' or lighter-than-air flight. Cavendish himself did not at the outset evince much interest in this aspect of his work; but later, when the balloon was an accomplished fact, he regarded it favourably as a means whereby a more accurate and extensive knowledge of the properties of the upper air might be obtained.

Joseph Black was, as far as we know, the first man who definitely stated the connexion between Cavendish's demonstration of the properties of hydrogen and the construction of a balloon. About a year after the demonstration had been made, in 1767 or 1768, he declared that bladders filled with 'inflammable air' would rise in the atmosphere, but, as he said, he mentioned it only as 'an obvious and self-evident consequence of Mr. Cavendish's discovery'. Attempts have been made to credit Black with having made the first balloon by means of inflating bladders with gas, but he himself denied this. He declared that at one time he contemplated making such an experiment, but never actually did so. 'I certainly never thought', he added, 'of making large artificial bladders and making these lift heavy weights, and carry men up into the air.'

Tiberius Cavallo, afterwards the first historian of aeronautics, was also, it would seem, the first to experiment with a hydrogen balloon. After finding that paper was too porous to retain the gas, he proceeded to inflate soap bubbles with 'inflammable air', and observed that they would rise and float upwards to the ceiling of a room. Here was a simple and rudimentary balloon. Cavallo,

'tired with the expense and loss of time', gave up the experiments and proceeded no further. But the day of the balloon as a practical aeronautical device was now not far distant, though, strangely enough, hydrogen was not destined to be the first agency to lift it into the air.

§ 2

Like the first successful aeroplane, the first balloon was contrived by the united efforts of two brothers. Joseph and Étienne Montgolfier were the sons of a paper manufacturer of Annonay, in France. It has been said that their success was due to a 'happy accident',[1] and the idea first came to them from watching heavy clouds floating in the air; but this should not be allowed to give the impression that there was anything of an haphazard nature about their achievement. Both the brothers Montgolfier were students of the physical sciences, and it was the reading of Priestley's *Experiments and Observations on Different Kinds of Air* (published in 1774 and translated into French two years later) that first stimulated them to take an active interest in aerostatics. Incited by the knowledge thus gained of the nature of the atmosphere and the properties of its component gases, they proceeded to make practical experiments. In November 1782 they successfully flew small paper balloons filled with hot air; in the April following they repeated the experiment with a larger device; and on the 5th June 1783 gave their first public demonstration.

The balloon on this occasion measured 110 ft. in circumference, was spherical in shape and inflated, as in their previous experiments, with heated air from a fire of chips and shavings. It rose to a height of 6,000 ft. and travelled nearly a mile and a half before it lost its buoyancy owing to the cooling of the air. This truly great and novel happening aroused immense enthusiasm and was soon being eagerly discussed in scientific and fashionable circles in Paris. The physicist Charles at once perceived the superior

[1] Sir Walter Raleigh, *The War in the Air*, vol. i.

properties of hydrogen over hot air, and assisted by two mechanics named Robert, he constructed a small silk balloon which, filled with 'inflammable air', made a voyage of fifteen miles.

Meanwhile the Montgolfiers were summoned to the French court at Versailles, where they successfully liberated a large 'hot air' balloon, in the admiring presence of the ill-fated Louis XVI and Marie-Antoinette, who, amid the autumnal splendours of the old régime, gazed with wonder at this picturesque and innocuous product of the modern mind. To add a piquancy to the occasion and also to test the effects of the upper air upon living organisms, a sheep, a cockerel, and a duck were sent up in a basket attached to the balloon. The sheep (almost certainly the first ruminant to achieve flight) and the duck descended, after being carried to a height of 1,500 ft., none the worse for their peculiar adventure, but the cockerel was found to be suffering some slight indisposition. At first it was believed that the rarified atmosphere of those high altitudes had adversely affected its respiratory organs, but it was later conclusively proved to have been trodden upon by the sheep.

Ballooning now became the craze of the hour in Paris, and a keen rivalry sprang up between the believers in the hydrogen balloon of Professor Charles (for the most part scientists) and the adherents to the original 'hot air' method of the Montgolfier brothers.

On the 15th October a young enthusiast, Pilâtre de Rozier, ascended in a captive Montgolfière (as the 'hot air' type of balloon came to be called), and on the 21st November, together with the Marquis d'Arlandes, he accomplished the first free flight from the gardens of the Château de la Muette. Sailing over Paris at a height of some 300 ft. they landed safely, after some anxious moments when the fire maintaining the supply of hot air set fire to the fabric and was with difficulty extinguished, having made a voyage of over five and a half miles. Thus man made his first assault upon the hitherto inviolable precincts of the air.

A few days later Professor Charles, accompanied by one of the

Roberts, rose and travelled twenty-five miles in a hydrogen balloon, from Paris to Nesle, where, on dropping his passenger, he was borne upwards in the lightened balloon to a height of two miles—an alarming experience which, it is said, completely satisfied the Professor's ambitions as an active aeronaut. The balloon used on this occasion differed little in essentials from the later perfected free balloons of modern times—the valve, the net, the use of ballast, and other practical devices were present in it. It has been truly said that 'under the hand of Charles the balloon as an aeronautical instrument was produced with a degree of completeness that made further essential progress difficult'.[1] Later devices, such as the trail rope, and minor scientific inventions, lessened the dangers of ballooning and increased its effectiveness within its limitations; but they did little to extend the restricted field of enterprise in which the balloon could be employed.

Balloon ascents now became frequent not only in France but throughout Europe. For some time the rivalry between the 'hot air' and the hydrogen balloons continued; but the manifest drawbacks to the Montgolfière type—such as the difficulties of maintaining a supply of heated air and the dangers of combustion—eventually led to its disappearance. Blanchard, perhaps the greatest of the pioneer balloonists, made ascents in many European capitals, using balloons inflated with hydrogen, and on the 7th January 1785 he succeeded in crossing the English Channel. Pilâtre de Rozier, who had long been contemplating this feat, endeavoured to repeat it in the same year, in a balloon that aimed at combining the two principles of 'hot air' and 'inflammable air' in the same machine. Before he had left French territory behind, however, the double balloon caught fire, and the young aeronaut—the first man to ascend into the air—was killed.

[1] J. E. Hodgson, *The History of Aeronautics in Great Britain.*

§ 3

At this point it may be of interest to give a short account of the beginnings of practical aeronautics in Great Britain. Notwithstanding the important, indeed the vital contributions made by her scientists to what we may call the chemistry of aerostatics, England took no hand in the actual invention of the balloon—an achievement that belongs solely to France. Indeed, when the stories of the Montgolfiers' balloon became known in England they were received with indifference and even a degree of scepticism both by scientific men and the general public. The English are in some respects an unduly sceptical people and are certainly prone to temper their enthusiasms with a degree of levity. It is in their nature to subject an innovation to the searching ordeal of ridicule before they are prepared to accept it at its own valuation. Their attitude to the balloon was, moreover, doubtless influenced by the fact that it came to them from abroad—since the ideas and enthusiasms of foreigners are always in danger of being regarded by the ordinary Englishman as slightly comical. Thus the balloons that had so thrilled the Parisians became in England a matter for humorous allusion. In the case of the men of science there may or may not (there is no definite evidence on the point) have been added a tinge of jealousy.

However, the sending up of small experimental balloons soon became a fairly common practice. An Italian sailor, Zambeccari, who had come to England to avoid the displeasure of the Inquisition in Spain, constructed a small balloon with the help of a fellow-countryman and released it privately in London on the 4th November 1783. It was seen in its flight by a great number of people and aroused much interest in the neighbourhood. He followed up this experiment by making a larger balloon which was released in the presence of the public at the Artillery Ground at Moorfields, on the 25th November. Both these balloonets were of the Montgolfière, or 'hot air' kind. On the day following a

Swiss scientist, Aimé Argand, gave a demonstration with a tiny hydrogen balloon before His Majesty King George III and the Royal Family at Windsor. The King—who had previously offered a sum of money to the Royal Society for the purpose of making experiments with balloons, with no result beyond a respectful refusal—was delighted with the device, holding the string to which it was attached and playing with it for some time; finally watching its ascent into the sky with amiable approval. It is pleasant to be able to record that George III, upon whose intelligence and foresight historians have lavished but little flattery, seems to have been almost the first Englishman to take a genuine interest in the balloon or show any desire to assist its development. Similar displays with small balloons followed, in London and other parts of the country.

However, the interest aroused by these demonstrations would seem to have been of a mild sort, and no one, least of all the men of science, was fired with the ambition to build a large balloon capable of lifting a man. A small book entitled *The Air Balloon: or, a Treatise on the Aerostatic Globe*, appeared anonymously in November 1783, describing the ascent of Pilâtre de Rozier in France, and giving a simple account of the principles and possibilities of the balloon; otherwise practically nothing was written in England on the subject.

In the spring of 1784 certain projects for balloon flights were announced, but they sprang apparently more out of a hope of making financial profit by staging a novel spectacle than from any serious interest in the science of aerostatics: they achieved no success.

James Tytler, a Scotsman who had previously studied under Dr. Black at Edinburgh, was the first man to make a genuine attempt at aerial flight in Great Britain. Of an adventurous disposition, Tytler had failed in the medical profession and had been engaged in editing the second and third editions of the *Encyclopaedia Britannica.* In the summer of 1784 he raised money in

Scotland by subscriptions and began to construct a 'hot air' balloon. His two first attempts to ascend, early in August, resulted in complete failure: on the 15th August, after being compelled to remove the 'gallery' supporting the stove, he tried again. On this occasion the balloon, filled with hot air, rose with Tytler, was partially checked by a rope, and after a brief plunge through the air, fell to earth. Tytler, according to his account, certainly left the ground, but it can scarcely be claimed that he made a genuine flight. Later he made further attempts, but ill luck persistently attended him, and in the next year his last balloon was completely destroyed by a sudden storm.

While Tytler had thus been courageously but ineffectually trying to invade the air in Scotland the interest of Londoners had been aroused by the promise of a magnificent balloon ascent by a gentleman styling himself the Chevalier de Moret. A large balloon was constructed, elaborately decorated and filled (it would seem) with ordinary air. The public were invited to feast their eyes on this attractive spectacle at the nominal charge of one shilling a head. Soon afterwards an ascent was promised and people thronged to the neighbourhood of Five Fields Row, Chelsea, to witness the novel phenomenon. The balloon refused to rise and was completely destroyed, either by fire or by the angry and disappointed crowd. The Chevalier was himself fortunate to escape a like fate. Another attempt at flight by Dr. John Sheldon, a scientist of some repute, in a balloon built by a man named Keegan, was equally unsuccessful.

These failures, particularly in view of the grave suspicion of fraudulent imposture attending the activities of the Chevalier de Moret, submerged the balloon under a cloud of mistrust and ridicule. It was only the striking success of the Italian, Vincenzo Lunardi, that at last compelled the people of this country to take the French invention seriously and to admit the extent of its triumph.

Vincenzo Lunardi was born in Italy in 1759, and came to England as a member of the Neapolitan Embassy with Prince Caraminico.

He possessed no special scientific knowledge, and his enthusiasm for ballooning seems to have been the outcome of an adventurous temperament and a love of excitement and novel experiences, together with a keen desire to win distinction and fame as the first man to make a balloon ascent in England. He appealed for subscriptions to a fund to be devoted to the construction of a balloon, and although the response disappointed him, a number of prominent men, including Sir Joseph Banks, interested themselves in the scheme and gave financial assistance. The popular reaction against aeronautical enterprises caused by the Chevalier de Moret's fiasco led to further obstacles being placed in his way, but at length a spherical balloon constructed of oiled silk, measuring 103 ft. in circumference, and capable of inflation by means of hydrogen gas, was ready and permission to attempt the ascent from the Artillery Grounds, Moorfields, reluctantly given by the authorities.

September 15th, 1784, was the day selected for the trial, and a vast concourse of people, impelled by curiosity, and mostly sceptical of both the virtues of the balloon and the good faith of its owner, assembled round the spot. Lunardi well realized how critical was his situation. A failure, he knew, would rouse the latent hostility of the spectators, and a riotous attack upon himself and the balloon would almost certainly follow. The weather was perfect for the attempt, and many illustrious persons, including the Prince of Wales, Pitt, Fox, and other prominent statesmen and ladies of distinction journeyed to witness it.

A miscalculation led to imperfect inflation of the balloon, and Lunardi was compelled to abandon his intention of taking up a human passenger with him. At length all was ready, and the aeronaut, bidding a precautionary farewell to his friends and accompanied only by his dog, his cat, and a number of pigeons, entered the car. The balloon was released and rose with a slow and stately motion over the heads of the astonished multitude. At sight of this amazing spectacle the distrust and unfriendliness of the people were instantly dissipated : thunderous cheers were wafted

upwards to the steadily mounting balloon, and in a moment the young Italian was become as great a popular hero as ever his romantic temperament could desire.

'As a multitude lay before me of a hundred and fifty thousand people,' he wrote afterwards in *An Account of the First Aerial Voyage in England*, 'who had not seen my ascent from the ground, I had recourse to every stratagem to let them know I was in the gallery, and they literally rent the air with their acclamations and applause. In these stratagems I devoted my flag and worked my oars, one of which was immediately broken and fell from me. A pigeon, too, escaped, which with a dog and cat were the only companions of my excursion. . . . All the moving mass seemed to have no object but myself and the transition from the suspicion and perhaps contempt of the preceding hour to the affectionate transport, admiration and glory of the present moment, was not without its effect on my mind. . . . A gentlewoman, mistaking the oar for my person, was so affected with my supposed destruction, that she died in a few days.'

Lunardi, in his first aerial voyage in Great Britain, traversed a distance of some twenty-four miles and came safely to earth at the end of it. The popular imagination was fired by the exploit, and balloons and the Flying Man became the talk of the country. As in France a year earlier, people could think and talk of nothing else. Even Dr. Samuel Johnson, now an old man, was pleased with Lunardi's success, though he tempered his enthusiasm with a critical estimate of its true importance.

'We now know a method', he wrote, 'of mounting into the air, and, I think, are not likely to know more. The vehicles can serve no use until we can guide them ; and they can gratify no curiosity till we can mount with them to greater heights than we can reach without ; till we can rise above the tops of the highest mountains, which we have not yet done.'

Horace Walpole, too, modified his praises by asserting that he did not care to be 'divining with what airy vehicles the atmosphere will be peopled hereafter, or how much more expeditiously the east, west, or south will be ravaged and butchered, than they have been by the old, clumsy methods of navigation.'

Balloon ascents now soon became of comparatively common occurrence in various parts of Britain. Lunardi made many further 'flights', and the ascent of James Sadler, the first Englishman to navigate the air,[1] at Oxford on the 9th October, 1784, was the earliest of a series of courageous aerial journeys undertaken by him and other balloonists.

§ 4

It would be neither useful nor, indeed, possible in this small book to attempt individual mention of the many pioneering adventures in the air during the concluding years of the eighteenth century. A brief account of the activities of the free balloon and an estimate of its significance in the story of aeronautical progress will suffice to conclude this chapter.

The early optimistic hopes of the balloon's utility were soon to be disappointed. Throughout its career many attempts were made to discover a function which it could effectively fulfil. To the best of its limited ability the balloon served four purposes—those of reconnaissance in war, scientific investigation, the provision of a new and adventurous sport, and an attractive spectacle at resorts of pleasure.

The first war balloon was built by order of the Committee of Public Safety and used by the French revolutionary armies in 1794 in their campaigns against the Austrians on the Belgian frontier. Excellent reconnaissances were carried out from the balloon, and in at least one battle these contributed very largely to the French victory. Jourdan, the French commander, was greatly impressed by its value, and it is said that the effects of the balloon upon the morale of the enemy were considerable. The Austrians regarded it as a thoroughly unsporting method of waging war, such

[1] Some doubt has been expressed regarding this achievement, but Mr. J. E. Hodgson, in his *History of Aeronautics in Great Britain*, will admit of none, and his detailed account of the event appears to establish Sadler's claim conclusively.

as would be employed only by a revolutionary rabble like the one that was defeating them so effectively.

However, the inherent defects of the balloon as an engine of war soon began to make themselves felt. These were chiefly the difficulties attending its transport and inflation in the field, which were almost insurmountable in a war of rapid movement and tended greatly to reduce its reliability. These handicaps continued to limit the employment of balloons in warfare throughout the nineteenth century. Balloons were used with success in the early campaigns of the American Civil War, during the siege of Paris in 1871 (where the conditions were more favourable), and by the British Army (who had begun military experiments with balloons in 1878) in Bechuanaland, the Sudan, and South Africa. However, it cannot be said that the balloon ever became a recognized and essential factor in warfare. Its disabilities remained ever with it.

Early attempts were made to use the balloon in the interests of science, but beyond the fact that previous calculations of the composition of the upper air were shown to be generally correct, little was achieved. Gradually the balloon fell into the hands of enterprising showmen and spectacular ascents (our language had not yet been enriched by the term 'stunt') helped to preserve it from oblivion. About the middle of the nineteenth century further efforts were made to gain scientific knowledge by balloon ascents, but though great heights were sometimes reached (in one instance 37,000 ft.), the results obtained were of only small importance. Ballooning was practised by a few enthusiasts as an exciting sport towards the end of the nineteenth century, but by this time the energies of those interested in aeronautical science were being directed more and more towards the invention of the aeroplane and the dirigible airship, and the days of the free balloon were numbered.

Dr. Johnson's observation that 'the vehicles can serve no useful purpose till we can guide them' went straight to the essential

weakness of the balloon. Balloons might present agreeable spectacles ; ballooning might provide a thrilling sport for the few ; in some small and restricted ways the free balloon might be employed in the services of science or warfare ; but it could never in itself prove a great or progressive agent of material civilization. Benjamin Franklin, when asked what was the use of the balloon, made his famous retort, 'What is the use of a new-born infant ?' The reply was born of foresight and vision, but his interlocutor might perhaps have been justified in inquiring further what really *was* the use of a new-born infant if it persisted in its infantile helplessness, mewling and puking, so to say, through a long and ineffectual existence.

The inventors and early demonstrators of the balloon can claim, it is true, only a strictly limited triumph, but it would be ungrateful and unjust to deny to these brave pioneers their rightful place in the history of man's conquest of the air. They prepared the way for the dirigible airship of a later period and may fairly claim it as their godchild. But more than this, they stimulated popular interest in the wonder and romance of human flight to a degree it had never approached before. What Wilkins and his associates did for the small world of science, the Montgolfiers, Charles, Rozier, Lunardi and their brethren did far more vividly and boldly for the ordinary man. Popular interest in aeronautics might hereafter fluctuate from time to time, but it could never descend again into the depths from which the balloon had lifted it. Throughout the nineteenth century there must always have been many who felt with complete assurance that the full and effective conquest of the air was only a matter of time. The balloon converted a remote and intangible speculation into a real and practical goal of endeavour.

IV

The Beginnings of the Aeroplane

§ 1

We have seen that at the end of the seventeenth century little progress had been made towards the actual devising of a heavier-than-air flying-machine, although several acute and imaginative minds had endeavoured to grapple with the subject. Leonardo da Vinci had brought the problem within the scope of scientific research by his statement that the questions to be solved were essentially mathematical and mechanical. Bishop Wilkins had preached the doctrine that to creative science nothing need be regarded as impossible and had aroused the interest of learned men in the problem of flight. Then Borelli interposed with a convincing demonstration that man could never fly as the birds fly by means of muscular energy. Obviously little more could be done until some new line of advance should be discovered that could steer clear of the impassable barriers indicated by Borelli.

Aeronautical science during the eighteenth century made no important advance towards the invention of the aeroplane. When the nineteenth century dawned the world was certainly a hundred years nearer in time to the first successful flight by the Wright Brothers, but there were no signs or portents in the sky to indicate the fact. It is true that the steam-engine was in process of being invented—that, as will later be seen, was the one real contribution offered by the eighteenth century to the solution of the problems of flight—but none had as yet claimed it as an ally in man's contest with the air.

There were perhaps three main reasons for this lack of progress. Firstly, the theorists and would-be inventors who devoted attention to the subject still toyed with the idea of wing-flapping devices necessarily dependent on muscular power; secondly, the balloon, during the latter part of the century, did much to distract

attention from the problems of heavier-than-air flight; and thirdly, no effective means of mechanical propulsion had appeared to replace the inadequate force of human muscles. However, there are a few names, during the period, that deserve a passing mention.

In 1742 the Marquis de Bacqueville made one of the few practical attempts at mechanical flight that this century produced. His aim was to fly, or perhaps glide, across the river Seine at Paris, taking off from an upper room of his house which overlooked the river. We have little accurate knowledge of the device that he used, nor is it possible to say whether it was built according to any genuinely scientific principle derived from experiment or research: he attached some kind of wings or ' aeroplanes ' to his arms, which served only to mitigate the severity of his fall and preserve his life at the cost of a broken leg. It seems probable that the place of the marquis is with such adventurous characters as the Saracen of Constantinople and John Damian, rather than among the constructive aeronautical scientists whose work slowly but surely led to successful flight. We may esteem his courage and imagination.

Emmanuel Swedenborg (1688–1772), a restless and erratic genius whose mind continually wandered in strange fields of thought, at one period dwelt on the problems of flight and constructed in theory a heavier-than-air flying-machine. The plan was cumbersome and impracticable and is of interest only so far as it shows that men were displaying an increased capacity to grasp the difficulties of the problem before them; this was especially noticeable in Swedenborg's understanding of the need for a device to secure stability in his machine. 'Place a balance or beam below,' he wrote, ' hanging down perpendicularly for some distance with a small weight attached to its end, pendent exactly in line with the centre of gravity. . . . This would serve to restore the balance of the machine if it should lean over to any of the four sides.' This need for maintaining an equilibrium was a grave difficulty which all the later builders of gliders and aeroplanes had to face.

The work of Paucton (1736–98), a French mathematician,

followed by the joint efforts of Launoy and Bienvenu, is of greater interest and calls for somewhat closer examination. Paucton, in 1768, published a treatise entitled *Théorie de la vie d'Archimède*, in which a proposed flying-machine is described. It was to be fitted with two mechanical propellers, one to lift it vertically and one to drive it along in a horizontal direction. The idea of a vertical propeller is, of course, the idea of the helicopter which much earlier had engaged the attention of Leonardo da Vinci. It will be well at this point to explain and briefly discuss the principle of the helicopter.

Avoiding anything in the nature of a technical exposition, it may be said that the helicopter method of flight relies upon a revolving propeller, the blades or wings of which rotate in a horizontal plane, thus beating and compressing the air downwards beneath them and causing the machine to which the propeller is attached to be forced straight up from the ground. This principle is theoretically sound, and small model helicopters can be made to rise freely in the air in this way. The weakness of the helicopter as a means of attaining human flight lies in the fact that as the weight to be lifted increases, the area of air surface on which the blades of the propeller must act to give the required lift and maintain the weight in the air increases so greatly and disproportionately that the size of the propeller must needs become impracticably large. Thus it is that no machine capable of carrying a man has yet been devised on the helicopter principle alone.

Paucton calculated the force needed to lift his machine from the ground and believed that it could be provided by his vertically mounted propeller (which he termed a *pterophore*); then he proposed to drive it forward in any desired direction by means of his second propeller, horizontally mounted, and rotating in a vertical plane. Unfortunately his plan was based on a misconception. When the weight of a machine is resting on the ground, only a limited force is needed to lift it; this Paucton's helicopter, or *pterophore*, might have produced. As soon, however, as the weight

is clear of the earth and loses its support, a like force is needed merely to maintain its position in the air, and a much greater force is required to raise it higher. This additional power Paucton had failed to provide.

It may be said at once that the helicopter, although a theoretically sound aeronautical device, lay outside the line of development which was to lead to the evolution of a successful flying-machine, and so does not directly concern us here. This by no means implies that attempts to develop the helicopter must necessarily be fruitless or are founded upon a fallacy. Any one who dares to prophesy concerning the future of aeronautical science in a dogmatic fashion is courting disaster, and it is at least probable that the helicopter, in conjunction perhaps with the aeroplane, will yet achieve pronounced successes. But the object of this book is to tell the story of man's actual conquest of the air, not to speculate on the manner in which that conquest may ultimately be extended; and in that story the helicopter plays no significant part.

Paucton confined his activities to expounding the theory of his *pterophore*, but he was followed by Launoy and Bienvenu, who in 1784 exhibited before the French Academy of Science a small model flying-machine designed on principles somewhat similar to those he had put forward, and demonstrated its ability to rise in the air. It is unnecessary to do more than mention the 'flying carriages', constructed by Canon Desforges and Blanchard (later to become a famous balloonist) as, lacking a sufficient motive power, they had no chance of success.

The flying-machine designed by C. F. Meerwin, an architect of Karlsruhe, at about the same time, is rather more interesting because the inventor exhibited the true scientific method, though he achieved no effective result. He is the first man known to have attempted to calculate the actual area of wing surface that would be required to support the weight of a man. He estimated that if a machine carrying a passenger weighed 200 lb., a wing surface of about 126 sq. ft. would be sufficient to sustain it—a calculation that

was afterwards shown to be approximately correct. There is no doubt that Meerwin pursued his investigations in an intelligent and thoroughgoing fashion: it was by methods such as his that the many problems of the air were ultimately solved.

The eighteenth century, as has been said, saw little actual progress made in the direction of heavier-than-air flight, though it produced a few interesting and intelligent students of the subject. One may see by the way they approached the question how scientific enterprise and the scientific method were rapidly permeating the Western mind, marshalling the forces of the human brain, as it were, for a new assault upon the guarded secrets of nature, providing it with new weapons and training it in increasingly effective methods of attack.

The nineteenth century started off with one great advantage. The discovery of steam power changed very considerably the problem which aeronautical science had to solve. With the knowledge of this great motive power men could regard the difficulties of flight from a new mental angle—could found their theories upon new and more hopeful premises.

§ 2

When it was seen that the invention of the balloon had not really solved the problem of flight there came a certain reaction against it, and men began again to think of some other means by which a more complete success might be obtained. This was especially the case in England, where the balloon was in general less esteemed than in France. Perhaps this was the reason why England contributed so largely to the progress in aeronautical science made in the early part of the nineteenth century. Certainly during this period our countrymen were foremost in the endeavour to devise a heavier-than-air flying-machine, and it may be said without exaggeration that we must go back to the work of Leonardo da Vinci to find new ideas of a significance that can compare with

those that were evolved at this time. Towering above his contemporaries and indeed above all his predecessors during more than two hundred years stands the figure of Sir George Cayley, the 'father of British aeronautics', who first expounded the true principle of the aeroplane on which modern heavier-than-air flight depends.

Boulton and Watt produced the first effective steam-engine in 1776. The influence of the steam-engine upon the progress of aeronautics is interesting. As a practical source of locomotive power it proved almost useless, owing to its great weight; but it is at least probable that if all the energy and inventive genius that has been employed in adapting the internal combustion engine to the service of flight had been directed towards the design of a sufficiently light and powerful steam-engine, a steam-driven aeroplane of a more or less effective kind would have eventually been devised. This, however, is merely a speculation which, thanks to the internal combustion engine, need not now be pursued. The importance of the steam-engine lies in the fact that it enabled men to assume the existence of a mechanical motive power far exceeding that of mere muscular energy. Thus Borelli's arguments against the practicability of human flight held good no longer, and the way was made clear for progress in directions hitherto hidden from sight.

Sir George Cayley was born in 1774 and lived until 1857. The period of his life saw a significant growth in aeronautical knowledge, an advance for which he was himself very largely responsible. A capable and imaginative student of science, he had been interested from boyhood in the problems of flight, and in early life he made many observations and experiments. In 1809–10 he published in the *Journal of Natural Philosophy* an essay 'On Aerial Navigation' which is by way of being a landmark in the history of aeronautical science. In it he discussed certain aspects of bird flight, and from the knowledge gained in his previous researches put forward a number of opinions and suggestions so pertinent and so sound that

they may be said to have formed the real foundations upon which all subsequent progress was built.

It is almost impossible to trace any idea to its source: we may think we have marked its very origin, but always if we search enough we find a glimmering or suggestion of it in some earlier mind from which in part it may have been derived. It would be palpably inaccurate to say that Cayley was the first man to investigate the resistance offered by the air to a given surface. As early as 1661 Hooke had read a paper before the Royal Society on 'Resistance of Air to Bodyes moved through it', while Newton and other scientists had made experiments in the same direction. We have seen that Meerwin had calculated the surface area necessary to support a man in the air, and many others whom we need not name had dealt with the problem during the eighteenth century. Nevertheless it was Sir George Cayley who interpreted the vaguely understood facts about the resistance of the air in a manner that brought them into their true relationship to aeronautics and showed that they were the *sine qua non* upon which all attempts at heavier-than-air flight must depend.

In his essay 'On Aerial Navigation' he first of all describes his observations of the flight of birds and hazards the opinion (first suggested by Bishop Wilkins) that flying demands much less expenditure of energy than was generally supposed. The importance of this observation lies in the fact that he had, consciously or otherwise, grasped the fact that all birds are to a certain extent natural gliders and receive an amount of help in maintaining themselves in the air from the resistance it offers to their wings quite out of proportion to the actual power they employ in their wing beats. That is to say, the resistance offered by the air to the wings of a bird in motion lifts it, or supports it without further application of energy until the necessary momentum is exhausted. Thus when once a bird is in flight its energy is used only to propel it forward and not to maintain it in the air as well.

Cayley then reiterates Borelli's statement that man will never be

able to fly effectively by means of wings worked by muscular effort. Although the vigorous repetition of this negative conclusion was still needed to warn investigators from wasting their time on a barren endeavour there was nothing new in it. Cayley, however, was not satisfied, as Borelli had perforce been, to tell men how not to attempt flight: he was also able to point out the direction in which they could most profitably employ their efforts. All that has to be done, he declared, is 'to make a surface support a given weight by the application of power to the resistance of air'. This single but so truthful sentence did more to bring mechanical flight within the grasp of man than everything that had been written on the subject since Leonardo da Vinci observed that 'a bird is an instrument working in accordance with mathematical law, which instrument it is within the capacity of man to reproduce'. Actually it contains a statement of the essential nature of that 'mathematical law' which had to be understood before a 'flying instrument' could be reproduced. The first successful aeroplane of the Wright brothers and the latest modern machine alike attained flight by making a surface support a given weight by the application of power to the resistance of air.

It may be well to explain as simply and concretely as possible what Sir George Cayley's remark really means and how it forms the basis of aeroplane flight. When a plane surface, such as is approximately represented by a stiff cover torn from a book, is held in a position horizontal to the ground and is then released, it is acted upon by two different forces. One is the force of gravity which impels it to fall earthwards; the other is the resistance offered to its fall by the air. The force of gravity, of course, easily overcomes the resistance of the air and the book cover falls to the ground. If, however, it is not merely allowed to drop perpendicularly, but when released is sent skimming by a wrist movement in a horizontal direction, while the force of gravity remains the same, the resistance offered by the air is much increased; the action of gravity is more powerfully counteracted and the book cover in

consequence takes longer to reach the ground. Now if it is again sent skimming through the air in the same direction, but is held so that the front edge is slightly tilted higher than the back edge, these two forces will still act upon it, but the resistance of the air will, if it is thrown with sufficient force, become greater than the pull of gravity and the cover will rise and continue to do so until its momentum decreases and with it the resistance of the air.

This, broadly speaking, is what enables an aeroplane to fly. The wings, tilted slightly upward (the measure of this tilt is known as the 'angle of incidence') correspond to the surface of the book cover. The propeller, worked by an internal combustion engine, supplies the motive power imparted in the other case by a jerk of the wrist. The aeroplane moves off into the wind until it attains a speed at which the resistance of the air exerts on the wings an upward force or 'lift' greater than the downward pull of gravity, and flight is obtained. In Sir George Cayley's words, a surface (the wings of the aeroplane) is made to support a given weight (the weight of the entire machine, engine and pilot) by the application of power to the resistance of air.

Of course, many intricate calculations must be made, and the nature and properties of this air resistance thoroughly understood before a successful aeroplane can be designed and made to fly, but the basic factors of heavier-than-air flight are those that Cayley expounded, and it is this that has led M. Alphonse Berget to affirm that his name must be written 'in letters of gold at the beginning of the history of the aeroplane'.

Four months after his first article appeared he contributed a second essay to Nicholson's *Journal of Natural Philosophy* in which he discussed further the problems of heavier-than-air flight. He realized that the shape of the machine would be very important, and, by reducing the *direct* resistance it offered to the air in its forward progress, its 'lift' or weight-carrying capacity would be proportionately increased without additional power being required. Thus he touched on the constructional problem known now as 'stream-

having a sharp surface
before the machine.

lining'. He further suggested that it might be an advantage to arrange the wing surfaces one above the other, as is actually done in the biplane and triplane, and he had some knowledge of the fact that a slightly concave or, as it is now called, 'cambered' formation of the wing surface would obtain greater 'lift' from the air resistance than a perfectly flat plane surface. Cayley saw that the steam-engine in its existing stage of development would be useless for providing the required motive force, owing to its great weight, and thought that some form of gas engine 'firing the inflammable air generated with a due proportion of common air under a piston' might be devised. This was a striking forecast of the principle on which the modern internal combustion engine works.

Cayley was not a theorist only, but devoted considerable time to observation and experiment. Apart from his careful and discriminating study of bird flight he constructed model gliders with which to test his ideas about the resistance of the air to a plane surface. Probably his attention was first drawn to this important subject when he realized how birds could sustain themselves in the air with so small an expenditure of energy; then he verified his theory by building small gliders and proceeded to obtain more exact information from his experiments which enabled him to make his further useful suggestions relating to details of design. One of his early gliders, which he described as resembling a 'noble white bird sailing majestically from the top of a hill to any given point of the plain below it . . .', developed sufficient lift to carry a man for a short distance.

He was interested in every branch of aeronautics. He had experimented with a helicopter model before turning his attention to the principle of the aeroplane, and later he studied the problem of applying mechanical power to the propulsion of balloons. When in 1843 Henson published an account of a proposed steam-driven flying-machine on the aeroplane principle, he returned to a consideration of heavier-than-air flight, criticizing the suggested design in a friendly manner, but not hesitating to point out its undoubted

defects. At the same time he himself published a design for an 'aerial carriage', but it was of less value than might have been expected from one who had previously expounded such sound and stimulating principles. He experimented further with gliders before his death in 1857.

Briefly to summarize the work of Sir George Cayley, it may be said that he did three important things for the advancement of aeronautical science. Firstly, he derided the idea that men could hope to fly effectively by trying to imitate the wing-flapping movements of birds with artificial wings agitated by muscular energy alone; secondly, he insisted on the importance of harnessing some form of mechanical power in the service of flight; and thirdly he enunciated the basic principle of the aeroplane. We might add that by his living and sensible confidence in the practicability of human flight he did much to inspire faith in those who came after him to work out and enlarge the ideas he had evolved.

In saying that Cayley enunciated the basic principle of the aeroplane it would be wrong to give the impression that he explained it as definitely or as clearly as we have endeavoured to do in the preceding paragraphs, in order that the reader might grasp the real significance of his statements. Similarly we need not suppose that he himself understood these principles as they are understood to-day. His work was necessarily incomplete and it was left for later investigators to discover the true importance of his theories and to put them into practice. These obvious qualifications, however, need not prevent us from honouring him as one of the greatest of the pioneers of aeronautical science and as the man who first saw the way by which flight would actually become a reality.

Another interesting student of flight at the beginning of the nineteenth century was Thomas Walker, who published a treatise shortly after Cayley's first essays appeared in *Nicholson's Journal*. Very little is known of him personally except that he was an obscure artist living at Hull, whence he later appears to have moved to Bristol, but his *Treatise on the Art of Mechanical Flying*, first

issued in 1810, was widely read and reprinted both in England and America. He appears to have been a man of humane interests, a devoted naturalist, and in particular an ardent lover of birds. Almost everything he has to say is based upon his observation of the flight of birds and the examination of their wing structure; his main contention being that since birds can fly, so could man if he could reproduce artificially the mechanical means with which they have been endowed by nature. He insists that flying is a purely mechanical process, thus reminding us of Leonardo da Vinci—whose writings on aeronautics, it should be remembered, were entirely neglected throughout the eighteenth and nineteenth centuries.

Thus far Walker's contentions were undeniably sound, and he was performing a valuable service to aeronautics by insisting on the fact that flying was a mechanical possibility. His weakness lay in underestimating the difficulties of the task. He was convinced that with the aid of mechanical devices men could easily fly by their own muscular energy. He described a machine that he had designed himself and which he was quite certain would fly. As he lacked opportunities for constructing it he was prevented from finding out his mistakes.

In 1831 he issued a new edition of his work which he had partly revised, and the design of his flying-machine was very considerably altered. He refers to 'flat passive surfaces large enough to reduce the force of gravity', and his drawing shows two such 'passive surfaces', or planes at front and rear of the body of the machine. He also makes a reference to the possibility of using steam power as a driving force, but dismisses the suggestion as impracticable owing to the unavoidable weight of the engine. It seems quite possible that in the period between the appearance of the first and second editions of the treatise, Walker's ideas had been in some degree influenced by the theories of Cayley regarding the properties of air resistance to a plane surface in motion. He mentions having read the 1809 essay when the first edition of his book was about to appear.

Walker was purely a theorist and apparently made no serious attempt to correct his ideas by practical experiment. Many of his inferences were incorrect, and his complete confidence in the adequacy of his knowledge—so frequently and annoyingly found in the works of the early pioneers—may be taken as a measure of his ignorance of the depths of the problem he so readily claimed to have solved. Nevertheless his writings aroused no little interest and undoubtedly helped in some degree to stimulate the mid-nineteenth century inventors who made the first attempts to construct power-driven machines. If his treatise had appeared some ten years earlier he would have won a high place among the theorists of heavier-than-air flight; as it was it suffers by comparison with the more brilliant achievements of Sir George Cayley which carried the frontiers of aeronautical science far beyond Walker's reach, and except that, as has been said, it helped to awaken interest in the subject, his work was of small practical value to the men who took up the problem where Cayley had left it.

§ 3

After the scientist, whom we may describe as one that gives material knowledge to his fellows, comes the inventor who applies the knowledge to a practical purpose. This seems to have been the almost invariable sequence in which our modern material civilization has been built up. Knowledge has meant power, in the literal and mechanical sense of that term. Thus we may expect to find that the knowledge of aerodynamics expounded by Sir George Cayley would be quickly seized upon by practical inventors eager to construct a flying-machine in accordance with his principles. This is exactly what happened, and in the middle years of the nineteenth century came the first serious attempts to build a true aeroplane driven by mechanical power. The attempts failed, in the sense that a successful flying-machine was not constructed, because the knowledge at the disposal of the inventors was not

yet adequate. A much more thorough understanding of the properties of the 'aeroplane' and a far more efficient motive power than the mid-nineteenth century steam-engine were required before the aims of men like Henson and Stringfellow could be attained.

One of the most interesting questions that can be asked about the aeroplane, or indeed about any new thing is, 'Why was it invented just when it was?' Why not five hundred years earlier, say, or fifty years later? It is a question for the historian to answer, and an answer can usually be found. We have tried to indicate how the modern spirit of scientific inquiry had been spreading through Europe since the time of the Renaissance, causing to be amassed a vast quantity of material knowledge of which previously the world had been ignorant. Many inquisitive minds had been drawn to investigate the problems of flight; and slowly, by their accumulated labours, an amount of information had been collected and placed at the disposal of any who might care to tackle this problem that had so fascinated the minds and imaginations of the human race from the earliest ages. Before the end of the nineteenth century the position was such that ultimate success was almost definitely assured.

We should understand, however, that this was not due solely to the work of such men as Sir George Cayley who contributed directly to the advancement of aeronautical knowledge. If Cayley's works and those of his predecessors had all appeared at the beginning of the sixteenth century it is inconceivable that an aeroplane would have been successfully flown by the first decade of the seventeenth century, or indeed much earlier than was actually the case; and this not merely owing to the lack of an efficient mechanical power of propulsion. In practical affairs it is very difficult for men to advance far beyond the general level of their age, and the generation that produced the aeroplane had additional advantages besides an improved knowledge of aero-dynamics.

By the middle of the nineteenth century the Industrial Revolution had greatly changed the characteristics of life in Western

Europe and the mental atmosphere in which men lived. The mechanical age was fully come and with it an all-round improvement in technical knowledge. Moreover, a new class of men, the mechanical engineers, had come into existence, and their number was increasing yearly. In the days of Sir Isaac Newton men who interested themselves in scientific and mechanical matters were as rare as poets, and perhaps rarer. Moreover they were students, theorists, one may almost say philosophers, who pursued knowledge for its own sake and were often only incidentally interested in the possible application of their discoveries to everyday life. Their chief concern was with principles rather than particulars. But the nineteenth century produced engineers almost as abundantly as the seventeenth had produced theologians, men to whom the known facts of science and mechanics were the familiar technique of their profession and who were daily brought in contact with machinery and mechanical processes. Thus was created the mechanical mind, a type so common to-day but almost unknown in preceding ages. These circumstances were naturally extremely favourable to a rapid development of technical knowledge and efficiency, since so large a number of capable and specialized minds were devoted to the advancement of man's mastery over material things. The general level of mechanical proficiency was raised immeasurably, and in consequence the possibilities of solving the mechanical problems of flight were proportionately increased.

The first attempts to build power-driven aeroplanes embodying the principles put forward by Cayley were made by William Samuel Henson and John Stringfellow. Born in the Midlands—Stringfellow near Sheffield in 1799, Henson, it is believed, at Leicester in 1805—chance led them both to settle at Chard, in Gloucestershire, where a friendship, based probably on their common interest in mechanical and aeronautical problems, grew between them. Henson later moved to London, but still kept up a correspondence with Stringfellow.

In 1840 Henson was engaged in experimenting with model

aeroplanes and in endeavouring to devise a miniature steam-engine light enough to be attached to them. In their later joint activities it appears to have been Stringfellow who was mainly responsible for producing the engine that they intended to employ. Two years later Henson patented a design for a monoplane on a scale large enough to make it a man-carrying machine. This aeroplane was never actually constructed and it would certainly never have been flown successfully, but the description of it in the patent proves that Henson thoroughly understood Cayley's principle of flight, which he expounded at the outset more fully and clearly, perhaps, than Cayley himself.

'If any light and flat, or nearly flat article be projected or thrown edgeways in a slightly inclined position, the same will rise on the air till the force exerted is expended, when the article so thrown or projected will descend; and it will readily be conceived that, if the article so projected or thrown possessed in itself a continuous power or force equal to that used in throwing or projecting it, the article would continue to ascend so long as the forward part of the surface was upward in respect of the hinder part...'

'Now, the first part of my invention consists of an apparatus so constructed as to offer a very extended surface or plane of a light yet strong construction, which will have the same relation to the general machine which the extended wings of a bird have to the body when a bird is skimming in the air; but in place of the movement or power for onward progress being obtained by movement of the extended surface or plane, as is the case with the wings of birds, I apply suitable paddle wheels or some other proper mechanical propellers worked by a steam or other sufficiently light engine, and thus obtain the requisite power for onward movement to the plane or extended surfaces....'

This, it will be recognized, is a true application of Cayley's principle to the making of a flying-machine, and describes accurately, though in general terms, the means by which a modern aeroplane achieves flight; in a limited sense it justifies the statement that 'the aeroplane as now known was the invention of Henson'.[1]

[1] H. Chatley, *The Problem of Flight*, quoted by J. E. Hodgson, *History of Aeronautics in Great Britain*.

It may fairly be said that Henson's design incorporated all the then known facts of aerodynamics that were later proved and developed by the inventors of the aeroplane. The technical details of the design were inadequate, as Cayley himself pointed out at the time, but even here Henson introduced many constructional features that are used to-day and which prove him to have possessed true inventive genius.

It is impossible to guess the extent, if any, to which Stringfellow had participated in the design of the proposed aeroplane; probably he engaged chiefly in trying to produce the 'steam or other sufficiently light engine' which was to supply the required motive power. Two other men, Frederic Marriot and D. E. Columbine, were taken into partnership with Henson and Stringfellow, and it was decided to promote a company for the commercial development of the *Aeriel*, as the proposed machine was named. This was an unfortunate move. It is doubtful whether either Marriot or Columbine had any real interest in aeronautics or a sufficient knowledge to form an adequate idea of the value of Henson's design. In 1843 an attempt was made to secure through Parliament an 'Act of Incorporation for the Aerial Steam Transit Company', and a prospectus was issued inviting interested persons to purchase £100 shares in the venture. The speculative nature of the enterprise was not denied, but such extravagant hopes of its success were expressed that one must feel regret that Henson and Stringfellow allowed themselves to be associated with them. The public very wisely refrained from subscribing to the venture, and although the *Aeriel* at first aroused some curiosity, ridicule quickly followed and the scheme fell into disrepute. Finally Henson and Stringfellow purchased the interests in the patent held by Columbine and Marriot and decided to construct a model at their own expense.

They worked together for some time, experimenting with various kinds of wing surfaces and supports, and endeavouring to develop a more efficient engine, but the model, when completed, refused to fly 'for want of proper adaptation of the means to the end of the

various parts ', as Stringfellow himself explained, and shortly afterwards Henson became discouraged and emigrated to America.

Stringfellow continued with the work alone, and early in 1848 had completed a new machine which was destined to be the first power-driven model aeroplane to fly successfully. 'The aero-planes of this model '—so wrote his son, F. J. Stringfellow, in a pamphlet entitled *A Few Remarks on Screw-Propelled Aero-Plane Machines*—' were about 10 ft. from tip to tip, and 2 ft. at the widest part, tapering to a point, slightly curved at the under surface, rigid in front, feathered at the back. Length of tail 3 ft. 6 inches, width in widest part 22 inches, surface in wings and tail about 14 ft. . . . The weight of the entire model, including water and fuel, was under nine pounds.'

The model was tested in a long room, an inclined wire being stretched for part of its length, along which the model was to begin its run. At the first attempt it failed, owing to the tail being set at too high an angle. The tail was then readjusted, the engine started and the machine set off down the wire, ' and, upon reaching the point of self-detachment, it gradually rose until it reached the farther end of the room, striking a hole in the canvas placed to stop it '. Later, an experiment at Cremorne Gardens before ' a party of gentlemen ' was equally successful, the machine darting off, after it left the wire, ' in as fair a flight as it was possible to make, to a distance of about 40 yards, when it was stopped by the canvas '.

This achievement may be held to mark the end of another stage in aeronautical progress, although Stringfellow's career as a designer of aeroplane models and light steam-engines was not yet completed. Undoubtedly this successful free flight of a model designed in accordance with Cayley's principle and under its own power was the most important and most encouraging practical result so far obtained in the direction of mechanical flight. It is Stringfellow's great contribution to the movement that was destined to produce the aeroplane as we know it, and upon this model his fame chiefly rests. We can better appreciate the progress made, however, if we

regard the work of Stringfellow in conjunction with that of Henson, and indeed their long and close collaboration makes it advisable to do this, notwithstanding the fact that Stringfellow secured his most striking triumph whilst working alone. Briefly, it may be said that the work of these two men carries forward the work of Sir George Cayley into the domain of practical aeronautics. In Henson's design for the *Aeriel* we see Cayley's principles made clear and applied to the construction of an actual machine. Henson might have indicated the significance of his work thus: 'Cayley put forward a principle of flight, of the soundness of which he had convinced himself by experiment: the design of the *Aeriel* is intended to show how a flying-machine embodying Cayley's principle may actually be constructed. As this design has not yet been tested by experiment, it is impossible to say with complete assurance whether it is correct either in its general conception or in its details.' In 1848 Stringfellow had advanced beyond this position, and might have summarized the results of his work thus: 'My friend Henson indicated the lines on which a machine embodying Cayley's principle of flight might be built: the successful flight of my model aeroplane, which in its general structure corresponded to his design, has proved that his conception was sound and may with advantage be made the basis of further study and experiment, though in detail his design was certainly inadequate. We are not yet in a position to build a full-sized aeroplane which will fly successfully, but we have indicated the general lines on which such a machine may be built, when the knowledge of aerodynamics shall have increased sufficiently to allow us to correct our errors in essential details of construction.'

This would have been a fair statement of the position in 1848, though, needless to say, it was not so clearly understood at the time. As the nineteenth century drew to a close the labours of a number of men had resulted in the accumulation of a large amount of this knowledge of practical aerodynamics that in 1848 was still lacking, and the day of the aeroplane was nearly come.

V

The Growth of Aerodynamic Knowledge and the Work of the Great Gliders

§ 1

The basic principles of heavier-than-air flight—or, more accurately perhaps, those basic principles on which heavier-than-air flight was first actually achieved—had now been determined and demonstrated. Much, however, had still to be found out about the air-plane, and the nature of the resistance offered by the air, before the most suitable form of wing surface could be approximately devised. Again, before an air-worthy machine could be constructed the problem of securing stability and similar structural difficulties, which had not concerned the enunciators of general principles, had to be solved.

The beginning of this period of research and experiment is marked by a significant event—the foundation, in 1866, of the Aeronautical Society of Great Britain, 'to foster and develop the Science of Aeronautics, which has stagnated for so many years, and incidentally therewith to increase our knowledge of Aerology'. To understand the general atmosphere in which this society was instituted it is necessary to review the position that the study and practice of aeronautics held at this time. It must not be thought that the work of men like Cayley, Henson, and Stringfellow had made any impression on the public, who remained either totally ignorant of it, or, at the best, completely unaware of its importance. Even among scientists, when their attitude of placid indifference was disturbed it was by expressions of ridicule and antagonism rather than encouraging interest. Practical aeronautics still meant only the balloon to the great majority even of those who took an interest in the subject, and the reputation of the balloon had collapsed. Except for Henry Coxwell, a bold and enthusiastic balloonist, men had come to realize that the balloon was not an

adequate flying device, and unless changed out of recognition, could never become one. There was, indeed, something of a reaction from the lighter-than-air principle in favour of heavier-than-air or mechanical flight, but the Aeronautical Society did not limit its interests to either branch. The small body of men who founded it, convinced that the free balloon had no future and might even be regarded as a hindrance to progress, felt that the road to success must lie in other directions, perhaps by supplying the balloon with a motive power, perhaps in the principle of the aeroplane. Their individual predilections and interests varied, but they had one common purpose, the advancement of the science of aeronautics to a point where true controlled flight should become possible.

It will be necessary to consider the work of certain individual members of the Society separately, but it may be well here to give a brief chronicle of its corporate activities and an estimate of the value of the work it performed.

The Aeronautical Society was the first organization supported by men of established scientific reputations to devote itself exclusively to the problems of flight, and by its mere existence it did much to give a new dignity and status to a branch of science which in general was regarded as the peculiar domain of cranks and impractical visionaries, if not of impostors. But more than this, it provided a focus point to which the energies of individuals might turn, and was able to bring to bear on the subject a sound and scientific criticism which tended to eliminate wild and impossible theories, and at the same time recognize useful ideas and incorporate them in the growing body of aeronautical knowledge. Undoubtedly its activities did much to increase the interest taken in aeronautics and to attract new minds to the study of its problems, though such a statement must be understood to have a limited application; popular opinion refused to take flying seriously, even long after it was an accomplished fact.

The Duke of Argyle was the first President of the Society, James Glaisher was Honorary Treasurer, and F. W. Breary Honorary

Secretary. The Council soon included a number of distinguished engineers, among them being Sir Charles Tilson Bright and Dr. William Fairbairn. Many other eminent gentlemen joined the Society. Largely as the result of the energy and enthusiasm of Breary the Society was active for some twenty years, after which it flagged somewhat. Breary, however, kept it alive until his death in 1896, a year that witnessed a revival of interest in aeronautics, since when it has continued to flourish and perform admirable service in the cause of flight.

From 1866 to 1882 the Aeronautical Society issued Annual Reports containing a summary of the year's activities, thus creating a permanent and accessible record of progress made. After 1882 the Reports were issued at intervals, until 1897, when the Society began to publish its *Journal*. Breary had become an ardent advocate of heavier-than-air flight, and the early work of the Society was chiefly useful in stimulating research in technical problems relating to the aeroplane. Thus the lack of aerodynamic knowledge which had hampered the work of Henson and Stringfellow was slowly being replaced by an increasing quantity of detailed information. The work was chiefly theoretical, but it proved very valuable to the exponents of gliding who were soon to carry the long assault upon the air to the threshold of success.

The first meeting of the Society, in June 1866, was memorable because on this occasion Francis Wenham read his important paper on 'Aerial Locomotion and the Laws by which Heavy Bodies impelled through the Air are sustained'. Wenham had long been keenly interested in mechanical problems—he was an engineer by profession—and during a journey up the Nile had spent much time studying the flight of birds. His work in the service of aviation was mainly theoretical, though he later undertook, on behalf of the Aeronautical Society, some experiments with planes, and he always insisted most strongly on the value, indeed the necessity, of practical experiment. Between 1866 and his death in 1908 he did much to improve the science of mechanical flight, both by his

own contributions and by his zeal and undaunted optimism, which insisted, in spite of the many failures of the time, that the aeroplane was indeed a practical flying device.

We have reached a stage at which it becomes increasingly difficult to describe the exact nature of the advance made by the efforts of individuals because, the main principles of the aeroplane being understood, the new knowledge gained was chiefly of a technical nature, and to indicate its meaning and importance would require an exposition of aerodynamic technicalities which is outside the scope of this work. It must suffice to say that the value of Wenham's work lay firstly in the fact that he expounded Cayley's principle more fully and more clearly than any one had so far done; and secondly that he progressed further by pointing out that 'planes' fulfilled their function far more effectively if they were constructed in certain definite shapes. He discovered, for instance, that the pressure of the air on an inverted plane operates mainly in a narrow area just behind the front edge; he therefore advocated the use of long narrow planes and suggested, as Cayley had done, the possibility of placing the planes one above the other. He also expressed the opinion that a true flat plane derives less 'lift' (as it is called) from the air than a surface which is slightly curved near its front edge. The 'planes' of all modern machines are thus curved or 'cambered'. By such discoveries Wenham contributed much to the solution of those technical problems that were barring the way to successful flight.

Another member of the Society who worked along the same lines as Wenham was Thomas Moy. Lack of space forbids a detailed account of his efforts on behalf of mechanical flight: he knew that the principle of the aeroplane was a sound one and sought to remove the practical difficulties that hindered its successful demonstration. He constructed a number of model machines, the first of which is said to have raised itself a few inches from the ground, but the insufficiency of power supplied by his steam-engine prevented any more marked success.

In 1868 the Aeronautical Society promoted an exhibition at the Crystal Palace. Seventy-seven exhibits were entered, including model engines, aeroplanes, and 'airships'. Among them was a triplane model built by John Stringfellow, whose interest in aviation had been revived by Wenham's paper read at the first meeting of the Society. The model was not allowed to attempt a free flight, but it demonstrated that it possessed considerable properties of flight. Stringfellow was awarded the prize of £100 offered for the lightest engine in proportion to its power suitable for use in a flying-machine.

Thus throughout the second half of the nineteenth century the Aeronautical Society was steadily engaged in advancing the cause of flight, but the greatest work during the period was done by a number of men, in various parts of the world, who, though they may have owed something to the Society's inspiration, carried on their experiments for the most part outside the range of its activities.

§ 2

The aeroplane is a mechanical device: its principles may be stated theoretically and their practical application may be tested by experiment; a machine may then be built in accordance with the knowledge thus obtained. To-day such a machine will certainly fly, but in the nineteenth century this was not necessarily the case, for the simple reason that there was no one who knew how to fly it. For flight, though based on mechanical science, depends also on human skill. This is largely the case even to-day; it was an essential factor in the early days of the aeroplane, but it was a factor that had been neglected. Many men were engaged in finding out how to build a machine that would be capable of flight, and they were already within reach of success. It did not perhaps occur to them that such a machine would not fly itself—that man would have to learn to fly just as he must learn to ride a horse or a bicycle or to swim. It may be said that it was the aeronautical

scientists and engineers, men like Cayley, Henson, Stringfellow, and Wenham, who invented the aeroplane; but it was no less certainly the great gliders who learned how flight could be accomplished. They first understood that much was required of the man as well as of the machine, and without their work the aeroplane might have been an invention still-born.

There had been early gliders of whose methods and achievements we know little—Besnier in the seventeenth century and the Marquis de Bacqueville in the eighteenth—but they had been ignorant of the nature of their task and their work was not significant. Cayley himself had made experiments with a glider capable of lifting a man, but he seems to have used it merely as a means of testing his principle of the plane and not for the purpose of learning to fly. A more important but still subsidiary figure in the history of gliding was Le Bris, a French sailor, who during his southern voyages was attracted by the wonderful gliding abilities of the albatross. On one occasion he took the wing of an albatross that he had killed and 'exposed it to the breeze; and lo! in spite of me it drew forward into the wind; notwithstanding my resistance it tended to rise. Thus I had discovered the secret of the bird! I comprehended the whole mystery of flight'.[1]

Apparently without any scientific knowledge, and lacking acquaintance with the theoretical progress being made in England, Le Bris had stumbled upon the essential feature of heavier-than-air flight. Settling down ashore in France he proceeded to build an artificial albatross of a size he judged sufficient to lift the weight of a man. The body of the 'bird' was boat-shaped, and each wing, made to resemble as closely as possible the wing of the albatross, was 23 ft. in length, providing a total wing surface of 220 sq. ft. The leading edges of the wings were capable of being adjusted to various angles and a hinged tail was added. The adjustable parts of the structure were controlled by an arrangement of pulleys and levers.

[1] Quoted by Vivian and Marsh, *A History of Aeronautics.*

Le Bris decided to test his glider by having it towed into the wind by a horse and cart. Its 'lift' proved so effective that it quickly rose to a height of 300 ft., carrying aloft, not only Le Bris himself, but also the driver of the cart, who became entangled in the tow rope and hung suspended in the air, giving, it would seem, an additional and gratuitous stability to the machine, which continued to fly into the wind, finally covering a distance of some 200 yds. and landing safely. Later Le Bris tried launching himself from the edge of a quarry, but on this occasion the glider lost its balance and was destroyed, the pilot, thanks to his presence of mind, escaping with a broken leg. Twelve years later Le Bris made another *albatross* with money raised by public subscription. This was successfully flown, ballast being used instead of a human passenger, but finally it too was destroyed.

The French sea captain may be regarded as the first of the successful gliders, and his achievements were in themselves remarkable. Le Bris was a clever and courageous man, but his work lacked a scientific basis and it contributed little to the subsequent development of flight. He appears never to have considered fitting any sort of engine to his glider; probably he knew nothing of light steam-engines and perhaps was not sufficiently interested in engineering to apply himself to the problem of artificial propulsion.

Otto Lilienthal was the first man to practise gliding persistently and scientifically, as a means whereby the aeroplane might be perfected, and controlled mechanical flight actually achieved. Among the many who contributed to the ultimate success of the aeroplane he stands second in importance only to the Wright brothers; none of the pioneers who preceded the Wrights did more for the cause of human flight. Without his work, and especially without his example, it is doubtful whether the Wrights would have succeeded.

Otto Lilienthal was born in Pomerania in 1848, a date that looms large in European history as the year of revolutions. It is at least

possible, however, that the revolution in human affairs that this young German was to do so much to forward will prove of greater ultimate significance than all the popular commotions that caused thrones to totter and filled the rulers of a Continent with alarm. We cannot foresee as yet the full meaning of this revolution that has won for mankind the liberty of the air.

From boyhood Lilienthal's mind seems to have been fascinated by the problem of flight. He and his brother Gustav, who in youth shared Otto's enthusiasm, began to build themselves artificial wings whilst still at school. They started to make definite gliding experiments in 1867, but owing to a lack of aerodynamic knowledge they made but little progress. The scanty descriptions that remain of Besnier's 'gliding' apparatus seem to have formed the basis of their design at this period.

After the Franco-Prussian war, which interrupted the experiments, Gustav Lilienthal abandoned the task, but Otto, in 1871, set himself seriously to work. He realized that their previous attempts had yielded poor results because he and his brother knew next to nothing about the nature of the problem they were trying to solve, and still less about the nature of the element, the air, that they were attempting to subdue. Consequently he determined to make a prolonged and detailed study of the properties of wing surfaces in their relation to the air. Like all the great students of flight he went to the birds, the true masters of the air, to learn his lessons from them. With infinite patience he collected information: that vague phenomenon, the resistance of the air to an inclined surface, on which the earlier theorists had been content to rely, served well enough for those who were merely demonstrating the possibilities of flight. It was far too vague, however, far too much an unknown quantity, for any one who wished actually to fly. Otto Lilienthal recognized this, and he resolved to find out what this air resistance actually was, to express it as accurately as possible in clear figures. He then experimented with various kinds of wing surfaces and proved, what had previously only been tentatively

asserted, that the curved or 'cambered' wing gave more lift than the flat surface.

Lilienthal's work during this period was in the main too technical to be described in detail here; we may, however, try to gain an idea of its character. It will be remembered that by the middle of the nineteenth century enough was known about the principles of mechanical flight to enable Stringfellow to build a small model aeroplane that flew under its own power. Further progress was held up, partly, it is true, through the lack of an adequate engine, but more definitely because men were still working too much in the dark. They understood the main principle, but they did not yet know the conditions in which it might be applied. To employ an often misused term, they lacked the necessary *data*. This may be said to describe the situation at the time when the Aeronautical Society was founded. The subsequent investigations of Wenham, Moy, and others helped to supply this want of accurate information, but still something of a more practical nature was needed. They failed, in a sense, to make direct contact with the problems that remained to be solved, and as a result many of the problems evaded them simply because they never suspected their existence.

Lilienthal's efforts were similar in their aim, but they were much more thorough and workman-like. He differed from experimenters like Henson and Stringfellow in that his primary desire was not to build a flying-machine in accordance with certain principles, but actually to fly. The machine was to him the means, not the end. He was always ready to make use of ideas or of information derived from outside sources, but he complained that too much was done 'on paper, in projects, and in aeronautical papers and discussions'. His instinct told him that the real work must be done in the air itself. It must not be thought that Lilienthal disdained research into the theory of flight—much of his own work lay in this region; but he insisted that theory and practical application must be kept in immediate contact, must be regarded, indeed, as

a single process and never be allowed to part company. Only thus, he realized, could the practical problems of the air be tackled with useful results.

By 1889 he had completed a careful investigation of bird flight, and working on the knowledge thus gained, had experimented with curved surfaces, in order to arrive at an accurate estimate of their sustaining powers. In this year his book, *Bird Flight as the Basis of Aviation*, was published, in which he stated the results of his investigations and experiments. It was by far the best treatise on aerodynamics that had yet appeared ; and it may be regarded as the earliest 'text-book' that contains information useful to the modern designer. It contained a masterly exposition of many details of bird flight and their application to the science of aeronautics. It marks a definite advance, a further milestone on the arduous journey

To Lilienthal, however, it seemed merely the beginning of his labours, the necessary preparation for the real work he had set himself to accomplish. Fundamental principles and detailed calculations set out on paper were very excellent and necessary and very gratifying—on paper : in the untried region of the air itself their adequacy might be less complete. He determined to test them in the air—not with small experimental models, but by actual flight.

He made his first glider in 1891 ; the framework of the structure was peeled willow rods covered with a tough cotton fabric, giving a supporting wing surface of approximately 100 sq. ft. On this and other gliders—he was always trying new ideas to overcome the practical difficulties he encountered in the air—he made more than 2,000 flights before his fatal accident in 1896. At first he used to launch himself into the wind from a spring-board ; later he made use of convenient hills ; finally in 1892 he had an artificial conical hill 50 ft. high erected in a flat district near Berlin, with earth excavated from the bed of a canal.

He attached himself to the glider by thrusting his forearms

through padded tubes and holding fast to a cross-bar. Thus he sailed through the air with his legs hanging below the machine. He immediately met with marked success and was soon able to cover distances of a hundred yards, when the wind was favourable, and to secure reasonable control over his machine. Once assured that plain straightforward gliding through the air under favourable conditions was a comparatively simple matter, his main endeavour was to secure stability. His idea was that stability could be best obtained by the pilot moving his weight backwards and forwards or from side to side as occasion required. After a time, he asserted, such movements became instinctive and automatic, so that the experienced pilot maintains the balance of his glider in the air just as a cyclist easily and without conscious effort preserves the balance of a bicycle. In 1896 he wrote in the Aeronautical Annual, 'My experiments in sailing flight have accustomed me to bring about the steering by simply changing the centre of gravity'. He then describes the reasons that led him to construct his later gliders with super-imposed surfaces (that is, with the planes set one above the other as in modern biplanes).

'The flights undertaken with such double sailing surfaces are distinguished by their great height. . . . I often reach positions in the air which are much higher than my starting-point. At the climax of such a line of flight I sometimes come to a standstill, so that I am enabled while floating to speak to the gentlemen who wish to photograph me regarding the best position for the photographing. At such times I feel plainly that I would remain floating if I leaned a little to one side, described a circle and proceeded with the wind.'

This was written shortly before Lilienthal met his death. He was just about to attempt power-driven flight and had constructed a machine for the purpose. Before this was actually tested in free flight he appears to have made an effort to secure more automatic stability by means of a rudder to be worked by movements of the head. While testing this he apparently became confused and the machine crashed from a height of 50 ft., and Lilienthal was killed.

He must always be regarded as one of the greatest of the pioneers of flight. His actual achievements are thus briefly described in the *Encyclopaedia Britannica*: 'To Lilienthal in Germany belongs the double credit of demonstrating the superiority of arched over flat surfaces, and of reducing gliding flight to regular practice.' It is the example that he set, however, that constitutes his chief claim to honour. Not only did he arouse widespread enthusiasm and directly inspire the men who finally triumphed; he also indicated the true method by which the problem should be attacked. He was the first man to get into the air—to practise flying as a necessary preliminary to the construction of a power-driven flying-machine. In an article called 'Why is it so Difficult to Learn to Fly' he wrote as follows

'The method which is to lead to practical flight must be capable of development, be its beginning ever so primitive, and by it we must be afforded an opportunity of really skimming through the air, by which we may gain experience as to the stability of flight, the action of the wind, and safe landing, in order, by continual development, gradually to approach permanent free flight. Perfection cannot be forced immediately. It is because inventors require too much from their constructions that the positive results are so little. . . . Whoever loses sight of healthy development by continually increased experience, will never attain anything in this sphere. . . .'

This may seem obvious common sense to-day, but it indicates the essential difference in method that separated the two types of men who, in the last years of the nineteenth century, were striving to make the aeroplane into a true and successful flying-machine. We may perhaps describe these two types as the 'inventors' and the 'gliders' and we will have to compare their methods more fully later. The future lay with the gliders (as many think it still lies with them to-day), and while it is easy to be wise after the event, Lilienthal at least was wise before the truth of his assertions could actually be proved. It seems reasonable to suppose that but for the accident that cut short his career at so early an age, Lilienthal

would himself have succeeded in making a controlled flight in a free, power-driven aeroplane and have anticipated the success of the Wrights by some years.

The gliding experiments which Percy Pilcher carried out in England between 1895 and 1899, regarded only as further steps towards the realization of heavier-than-air flight, are somewhat overshadowed by the greater work of Lilienthal, but in themselves they were remarkable and, at the time, outstanding achievements. As a youth Pilcher served in the Navy, but at the age of nineteen he quitted the Service and became an engineer. He became interested in the practical problems of flight, and, presumably as the result of reading some accounts of Lilienthal's work in Germany, began to build a glider which, however, gave unsatisfactory results. This was in 1895; in the same year Pilcher visited Lilienthal and was permitted to make a number of glides on his latest biplane glider. Greatly impressed, and with additional knowledge, he returned to England and reconstructed the *Bat*, as he had named his machine, adding a horizontal tail plane and lowering the wing tips which had at first been exceptionally high. On this he began to make fair gliding flights, using later a tow rope to begin the flight, somewhat as Le Bris had done with his first *Albatross*. He built two more experimental gliders, the *Beetle* and the *Gull*, but though not unsuccessful they were not very manageable, the *Gull*, a large machine weighing 225 lb., proving impossible to control except in the calmest weather.

The last of Pilcher's gliders, the *Hawk*, was built by him in 1896 at Eynsford, Kent. The framework of the machine was made almost entirely of bamboo, the wings being attached to two vertical masts joined at the summit and centres by two wooden beams. The tail was stayed to the main frame by wires. In all the wing surface was about 180 sq. ft. An interesting innovation was an elementary form of 'undercarriage' designed to take the weight of the glider when resting on the ground.

The *Hawk* was far and away the best of Pilcher's gliders. In

1896 he made a perfect gliding flight of 250 yds. across a valley, towed only by a light fishing-line. Encouraged by this success, he began to make plans for fitting an engine to the *Hawk*, and some time was spent in an endeavour to trace a light engine which was rumoured to be in existence in America. In 1897 he made further gliding experiments from which he calculated that an engine of three, or at the most four-horse power would be sufficient to maintain his machine in flight. The internal combustion engine was now well established, but it was still unreliable and had not been modified to make it a suitable motive power for a still more or less hypothetical flying-machine. Pilcher decided to build an engine for himself. The designing and construction of this engine occupied the year 1898. In 1899 Pilcher was attracted by Hargreave's soaring kites, and apparently he had thought of incorporating some of these ideas in a new glider. However, in September 1899 he agreed to give a demonstration with the *Hawk* at Stamford Hall, Market Harborough. The weather was unsuitable, and at the second attempt a guy-wire snapped and the machine crashed. Pilcher died on the following day without having recovered consciousness.

In the main it is true to say that Pilcher did not advance the practice or theory of heavier-than-air flight beyond the stage to which it had been carried by Lilienthal. He must still be regarded as one of the great pioneers, and he should be honoured as the first Englishman who sacrificed his life to the cause of mechanical flight. His enthusiasm was contagious and his successful flights added to the world-wide interest in the subject which was beginning to grow in the last decade of the nineteenth century. In the face of the achievements of Lilienthal and Pilcher it was becoming increasingly difficult for the many sceptics to scoff at the few enthusiasts who declared, with growing assurance, that the era of genuine and controlled human flight was near at hand. As with Lilienthal, it may reasonably be claimed for Pilcher that had he lived he would himself have built and flown a power-driven

aeroplane. Their lives were a part of the price that the air exacted of men before it succumbed to their persistent onslaught.

In the meantime enthusiasm had been awakened in America, where there were many who soberly believed that mechanical flight was easily within the scope of human attainment. Apart from an interest in the balloon, America had contributed practically nothing to the development of elementary aeronautical ideas and principles; but towards the end of the nineteenth century, as the country became industrialized and, may one say, 'mechanicalized', it began to produce engineers and scientists with mechanical interests, and as in Europe, among them were some who found themselves fascinated by the problem of flight. The Americans have proved themselves good inventors; their men of science have frequently combined the imaginative vision which sees the possibility of a great achievement with painstaking industry and a clear-sighted appreciation of practical details that have enabled them to translate their ideas into a working reality. These characteristics were now to be turned to the problems of mechanical flight. At the moment we are concerned only with the American gliders who were the predecessors of the Wrights.

The work of Professor J. J. Montgomery, who was fatally injured in 1911, is a little difficult to place. He is reported to have experimented with gliders as early as 1884, when it was extremely unlikely that he could have been acquainted with Lilienthal's researches, since little was known of them until he began to make his sensational flights in 1891. On the other hand his most notable achievements, in which gliders were released from balloons, were not accomplished until after the Wrights had made their first power-driven flights in 1903. Montgomery aimed, according to his own account, at three things—equilibrium, complete control, and long continued or soaring flight. His usual method was to construct his machine, weight it with ballast, and then cast it loose from a height, either from a cable stretched between two 'mountain-tops', or, later, from a balloon. The machines would then auto-

matically find their balance and make long gliding flights to earth. On one occasion a young assistant of Montgomery's was killed when making a descent from a balloon, but his death is said to have been due to an accident, and not to a structural defect in the glider. As has been said Montgomery was himself killed when experimenting in 1911.

It is difficult to say what measure of success was achieved by Montgomery in his early experiments of what we may call the pre-Wright period. It does not appear that the Wrights were in any way influenced by his activities during the time of their own experimental work. No reliable account of his work seems to have been written before his own description appeared in 1910. He may perhaps best be regarded as a pioneer glider of much ingenuity and skill whose work lay outside the immediate path that led to the conquest of the air.

The other great American gliding pioneer was Octave Chanute. He had studied aerodynamic theory and was acquainted with the experiments being carried on by Lilienthal in Germany. In the year before the latter's death he himself began to make gliding flights on a machine similar to Lilienthal's. In the years 1896 and 1897, with a small band of helpers, he made hundreds of glides among the sand dunes of Lake Michigan. In the true manner of scientific research he carefully tabulated the results of all his experiments, made many notes on the varying strength and eccentricities of air currents, and applied the knowledge thus gained to the improvement of his gliders. These machines gradually assumed two distinct forms, the first being multiple plane gliders having five tiers of wing surfaces and a tail-piece, the other a biplane glider which was eventually found to be the more satisfactory. He ceased making actual experiments about 1898 and devoted himself to the theory of aerodynamics and to encouraging and assisting others who were tackling the problems of the air.

Apart from the value of the records of his experiments which

proved of great assistance to others who followed him, notably to the Wrights themselves, and in addition to the practical encouragement and help he gave to all who were genuinely interested in the subject of flight, Chanute made a definite improvement upon the work of Lilienthal. The weakness of the Lilienthal type of glider, he declared in a paper entitled 'Experiments in Flying', lay in its lack of stability. The method of securing balance by moving the weight of the pilot as necessity demanded appeared cumbersome, uncertain, and even inadequate. He aimed at securing at least a certain amount of stability inherent in the machine itself. A sounder and less dangerous system would seem to be one which corrected any loss of balance by having the wing surfaces adjustable, so that the centre of pressure might be restored. He eventually produced machines possessing a fair degree of stability. So safe were they, under good conditions, that Chanute would allow inexperienced friends to make short glides, and on no occasion did any accident result. Nevertheless, he did not consider that either his multiple surface gliders or his biplanes were sufficiently stable or air worthy to justify the attempt to fit them with engines and make power-driven flights. As has been said, he abandoned his gliding experiments and devoted himself to further theoretical research, possibly with the idea of returning to practical flying at a later period when his knowledge of aerodynamics should have improved.

Though Chanute's actual flights through the air were perhaps less impressive and less daring than those of Pilcher, his ability as a designer was certainly greater. He stands as the direct link between Lilienthal and the Wrights.

VI

The Unsuccessful Inventors

The story of the great gliders is really one of continuous progress that ended in the achievement of true power-driven flight ; and it would be but following the sequence of events if one passed from a review of the work of Lilienthal, Pilcher, and Chanute directly to the Wright brothers. However, while the gliders were bringing successful flight nearer and nearer to attainment, other men, with equal enthusiasm though with less success, were also attempting to solve the great problem. Before describing the ultimate triumph of the aeroplane, therefore, it will be well to make mention of the more important of these efforts.

These attempts differ from those we have considered in the preceding chapter in that their aim was to produce a fully fledged flying-machine that should be straightway capable of sustained power-driven flight, without either the machine or the pilot having had any actual experience in the air itself. The gliders were trying to ' evolve ' a flying-machine that would gradually become efficient as the result of long continued practice in the air. The ' inventors ', as we may conveniently style them for the sake of contrast, however much they might study the theory of aerodynamics and experiment with models, still sought to cut out this long and arduous apprenticeship to the air. This was undoubtedly the chief reason why all of them failed ; it was the only reason why Professor Langley (whose work, though it falls into the same final category as those of the other unsuccessful inventors, deserves special consideration and a special place in the history of aeronautics) just failed to achieve success.

These ' inventors ' may be separated into three classes. Firstly there were those whose efforts were foredoomed to failure either because they did not base their design on Cayley's principle of the aeroplane or else they were working at a time when no adequate

engine power was obtainable. In the second group were Sir Hiram Maxim and the Frenchman Ader, who built aeroplanes almost certainly capable of rising in the air, but almost as certainly incapable of sustained and controlled flight. Finally there was Samuel Pierpoint Langley, the most scientific and able of them all, who constructed an aeroplane and an engine which were later flown with complete success, but which failed at the time as the result of accidents really due to inadequate experience in handling such a machine.

About the time when the Aeronautical Society was founded in England, a similar movement, inspired probably by the same growing realization that the balloon was incapable of further development, led to the organization of the ‘ Société d'Autolocomotion Aérienne ’ in France, and a few enthusiasts turned their attention to the problem of heavier-than-air flight. Unfortunately, though there were strong advocates of the ‘ aeroplane ’ principle in France, much of the energy of this group was diverted to efforts to develop the helicopter, and less real progress was made here than in England, where men like Wenham, Breary, and Moy were steadily building up a sound body of aerodynamic knowledge. The three men chiefly concerned in the founding of this French Society and in furthering the cause of heavier-than-air flight were Nador, Ponton d'Amécourt, and La Landelle. Their aim was to build a large helicopter capable of lifting a man, but apparently owing to lack of funds the scheme came to nothing, although many successful models were made and flown.

Alphonse Penaud (1850–1880) was perhaps the greatest of the early French exponents of the aeroplane principle. He experimented first with the helicopter, but afterwards made a small model aeroplane, which he called a ‘ planophore ’, which in 1871 performed a successful flight before a meeting of the Société de Navigation Aérienne, the successor of the original Société d'Autolocomotion Aérienne. It was in almost all respects a perfect aeroplane. He later designed a full-sized machine, which, given

the necessary engine power, would almost certainly have been capable of flight. Penaud, handicapped by lack of encouragement, was unable to proceed further than the design, and his unhappy death in 1880 cut short a career that might have been truly brilliant.

The work of Lawrence Hargreaves, of New South Wales, is deserving of mention, if only for its diversity and unbounded optimism. He experimented with wing-flapping devices and endeavoured to design a suitable engine for use in flying-machines. His greatest success was the invention of the box-kite, in 1893, which, it will be remembered, attracted the attention of Pilcher, who had thoughts of employing the idea in a glider. Hargreaves was an enthusiastic student of flight who worked with no thought of personal gain or glory. He was one of the few men of his time who had complete assurance in the practicability of human flight.

In 1893 Horatio Phillips in England built and tested a full-sized aeroplane. The supporting surface, instead of being in the form of large wings, was obtained from fifty narrow wooden strips, like the slats of a Venetian blind. The machine was tested on a circular track, without a pilot, steam being used as a motive power. It was not allowed complete freedom, but sufficient 'lift' was obtained to raise the machine a few feet from the ground above the track for a considerable distance.

Apart from the great gliding flights the attempts so far described were purely experimental, the object being to test the machine rather than actually to fly. Clement Ader may be regarded as the first man to make a definite and genuine attempt to navigate the air in a power-driven heavier-than-air machine. Ader, a Frenchman of an inventive turn of mind, made a prolonged and courageous effort to construct capable power-driven aeroplanes. It is difficult, as will be seen, to estimate the exact degree of his success. As early as 1872 he had built an obviously impracticable machine on the 'wing-flapping' or ornithopter principle which was to be propelled by human power. Convinced of the useless nature of this

device, he began to consider the more promising possibilities of the aeroplane and travelled abroad in order to study the soaring flight of large vultures. Returning to France about 1886, he started to build an aeroplane with large bat-like wings to which was fitted a light steam-engine. This machine, named the *Éole*, was tested in 1890. Whether or no this machine actually made the flight of 164 ft. as Ader's friends claimed is, like his other alleged successes, a matter of doubt; what does seem certain is that the machine lacked stability and was uncontrollable, whether it ever rose into the air or not. It was wrecked during the trial. Ader reconstructed his aeroplane and in the following year was permitted to give a demonstration before the French Military authorities at Satory. Again the machine was wrecked and again the evidence as to whether it actually left the ground must be considered inconclusive.

The military authorities must have been favourably impressed with the result of the trial, for Ader received a grant of money to continue his experiments. In 1892 he constructed another machine which was not a success; and in 1897, with his third aeroplane, gave his final demonstrations. Again it is impossible to give a clear and satisfactory account of what took place. What testimony exists is conflicting.

The *Avion*, as Ader's new machine was named, was driven by two steam motors each of 20 h.p., which worked two four-bladed propellers. A light wheeled undercarriage supported the weight of the structure. A circular track had been prepared round which the *Avion* hoped to fly. The first trial took place in the presence of General Mensier, who declared that the *Avion* frequently hopped off the ground but did not ever actually fly. A second trial was arranged, and on this occasion, after progressing some distance, the machine was destroyed.

According to an account given by Ader himself the *Avion* started off rapidly along the ground, following the prepared track, and quickly began to lift itself into the air. A sudden increase of wind strength tended to force it from its intended circuit, and the

Avion, now flying clear of the ground, headed, in spite of the pilot's endeavours to bring it round, straight for a dangerous obstruction. Alarmed by his elevation and the speed with which he was approaching some posts that bounded the School of Musketry, Ader shut off steam and the machine plunged to earth and was wrecked. According to the official report, however, made public long after the event, the *Avion* never achieved more than a series of hops.

It has been a matter of controversy whether Ader's aeroplane actually ' flew ' or not. Ader was certainly convinced that it did and believed himself to be the first man to navigate the air in a heavier-than-air machine. It is impossible to accept this claim as established, and the question may be left as one that contains an element of uncertainty. The matter is not one of importance, and does not really affect the position of the Wrights as the true inventors of the aeroplane. Whether the *Avion* flew or merely hopped on its brief progress to destruction, it was certainly not a machine on which man could ever hope to fly to any real purpose, and no more efficient aeroplane was developed from it. Even if it attained momentary ' flight ' in a somewhat strained sense of the term, it must be set down as a failure.

There is a natural tendency to depreciate the work of Clement Ader because greater claims have been made for it than the actual facts appear to warrant. In reality, however, he was a courageous pioneer who made a gallant attempt to solve the baffling problem of flight and came very near to at least a measure of success. It is easy now to say that his methods were faulty and his machine inadequate for the purpose of sustained flight. Compared with later aeroplanes, even with the earliest of the Wrights' machines, it appears cumbersome and impracticable. Nevertheless at the time it certainly represented the best effort to produce a full-sized power driven heavier-than-air machine that had actually dared to attempt a free flight. For his skill as well as for his bravery, perseverance and faith, Ader deserves more generous praise than has usually been accorded him.

While Ader was engaged on his experiments, Sir Hiram Maxim in England made an ambitious attempt to construct what at that time must have been considered a mammoth aeroplane, driven by powerful steam-engines. Maxim, who had made himself acquainted with the aerodynamic science of his day, experimented first of all with models and with devices to test the qualities of air resistance to planes set at various angles. After a period spent thus, he began to build his great aeroplane. When completed, it was an imposing structure, measuring 50 ft. across the wings. Perhaps the most original part of the machine was the engine. Maxim considered that a steam-engine sufficiently light and yet powerful enough for his purpose was not an impossibility. No satisfactory attempt at a light steam-engine had been made in England since the time of Stringfellow, and constructional processes had undoubtedly improved considerably in the interval. The engine Maxim finally made was certainly a triumph of design; it did all that it was called upon to do. Its weakness lay in the fact that it required a very large aeroplane to contain it and support its weight, thus adding greatly to the structural difficulties. If Lilienthal found it difficult to secure stability in his light gliders, the task would be far more complicated in this more cumbersome machine.

When the aeroplane was ready for trial Maxim proceeded cautiously. He decided to run it first of all on a nine feet gauge rail without attempting flight, and had a set of heavy cast-iron wheels constructed to counteract the immense ‘ lift ’ that was to be anticipated from the wide wing surface and powerful engine. The machine even then tended to plunge into the air, and eventually was hurled completely off the track.

Maxim then constructed a second track, consisting of the original rails and a second safety ‘ track ’ of squared pine logs raised some two feet from the ground. The aeroplane was fitted with a set of light wheels on out-riggers. The idea was that when a certain speed was reached the iron wheels should keep contact with the lower track, while the aeroplane itself should be free to rise until

the wheels on the out-riggers made contact with the underside of the upper wooden track. Restricted flight would thus be possible. When the test was made, however, the aeroplane's 'lift' was so powerful that it broke clear of the upper track, and remained momentarily suspended in the air before it crashed to the earth, sustaining a certain amount of damage.

After this mishap Maxim abandoned his efforts to build a flying-machine (he later described his work in a book entitled *Artificial and Natural Flight*) and turned his inventive talents in other directions. Had he persevered he might well have won more noteworthy success, though it is unlikely that the machine he had built would itself ever have proved an airworthy craft. Like Ader's *Avion* it represents fairly accurately the stage that aerodynamic science had reached in the last decade of the nineteenth century. It was constructed on sound principles and was supplied with a fairly efficient motive power. The technique of aeroplane design, however, was not yet sufficiently advanced to permit of a machine being built in the workshops direct from plan ; experience in the air was required to remedy small but vital defects. Especially was experience needed in the control of an aeroplane in flight. One thing seems clear from the partial success obtained by Ader and Maxim ; that is, that if the internal combustion engine had not appeared, an adequate steam-engine would soon have been devised which could at least have enabled the aeroplane to demonstrate its ability to fly.

The work of Professor Samuel Pierpoint Langley stands in a different category from that of Ader and Maxim. Of them it is approximately true to say that they took the science of aerodynamics as they found it, endeavoured to construct flying-machines in accordance with the 'data' it offered them, and left nothing behind them but the record of their unsuccessful efforts. Others who followed them had to begin, not where they left off, but where they themselves had started. With Langley it was otherwise. Although he designed and built an aeroplane that some years after his death was shown to be thoroughly capable of flight, it is not

this that gives him his chief claim to renown. He was one of the most able students of the theory of heavier-than-air flight, and by painstaking investigations and experiments he brought the science of aerodynamics to a point beyond which theory itself could hardly be advanced until practical flying had become a reality. The Wright brothers owed nothing to Ader or to Maxim; their debt to Professor Langley cannot be denied.

Langley was a Professor of the Smithsonian Institute, at Washington, and he had already had a distinguished career as a scientist before he turned his attention to aeronautics. During his period as Professor of Astronomy at the Western University of Pennsylvania he began to make the first of his series of experiments which culminated in 1891, when he published his *Experiments in Aerodynamics*. It was the first genuine attempt to reduce the study of heavier-than-air flight to an exact science. Other people had experimented with various kinds of 'planes', had tested the resisting properties of the air, and had speculated, suggested, or made dogmatic assertions which might be, and indeed were extremely valuable to other students of flight; but no one before Langley had tackled these problems quite so scientifically or thoroughly as to translate them from speculations into mathematical formulae. Hitherto the science of aerodynamics, despite the constructive and progressive work of the Aeronautical Society, had been vague and disconnected; many vital truths had been grasped, but they had not been co-ordinated, often they had not been proved. Langley investigated the properties of the 'plane' and its relation to air resistance so thoroughly that he was able to express his results, not in general or speculative, but in definite mathematical terms.

It is a bewildering and almost impossible task to give a coherent and chronological account of the progress in aeronautical science made between the years 1880 and 1903. Apart from its technical nature, the various investigators were working independently of one another and often in ignorance of each other's existence. Progress might be made in one direction in, say, Germany, and in

another in America: combine these two results and they will form an important achievement far exceeding their significance considered separately. But it may be that they were not combined; that no one person was acquainted with them both. Langley and Lilienthal working together would have done far more than they actually achieved apart, but unfortunately they did not work together, and it is doubtful whether either received any practical assistance from the other, assistance which they would each have been only too willing to give. Again there was the atmosphere of uncertainty in which all these pioneers worked; however great his faith, no one could then *know*, as we to-day know, that the aeroplane was on the threshold of complete success. A temporary set back, an accidental failure due to some slight and insignificant cause might assume sinister proportions. There always existed the heartbreaking possibility that after all the sceptics and the scoffers were right and that heavier-than-air flight was beyond the reach of practical attainment. The margin between success and failure may often have been small, but it was none the less decisive and may well have proved insurmountable. This may explain the somewhat inconclusive nature of much of the work done during this period; often it stopped short where it might have been expected to proceed triumphantly.

Professor Langley was not handicapped by this latter difficulty. We may think of him as approaching the problem of flight scientifically, with an unbiassed mind, willing to accept any results from his experiments, whether favourable or unfavourable. As far as we know he started from the beginning, from Cayley's statement that in order to fly one had only 'to make a surface support a given weight by the application of power to the resistance of air'. He constructed a sort of revolving table with a long projecting arm from which he was able to suspend brass plates. When the arm revolved the brass plates swung through the air and he was able to measure accurately the resistance offered to their progress and the amount of 'lift' they obtained. The results surprised him. He

found that the faster the arm revolved the less weight the brass plates registered, ' until at a great speed they almost floated in the air '. His device enabled him to register the results of these experiments accurately in figures.

' Some mathematicians ', he wrote, ' reasoning from false data had concluded that if it took a certain amount of power to keep a thing from falling, it would take much additional power to make it advance. My experiments showed . . . that the faster the speed the less the force required to sustain the planes, and that it would cost less to transport such planes through the air at a high rate of speed than at a low one. I found that one horse-power could carry brass plates weighing 200 lb. at the rate of more than 40 miles an hour in horizontal flight.'

Thus, as he said, what had before seemed impossible now began to look possible

These discoveries were not altogether new; they would not greatly have surprised Wenham or Stringfellow. Many men had suspected them. But they were now demonstrated clearly and indubitably and accurately. Cayley's general principle was being reduced to figures.

This point marks the first stage in Langley's work. He had proved the efficiency of the plane as a lifting instrument when impelled through the air at a certain velocity. He had prepared statistical tables recording the effects of planes in motion through the air. He now set himself the definite task of proving that these properties of the ' plane in motion ' could be employed to make a power-driven heavier-than-air flying-machine. This brought him into contact with a new set of problems, this time of a more practical kind. Firstly there was the question of the ' prime mover ', the mechanical power which was essential to sustained flight; secondly there were structural problems, of which the most vital was the need of stability. Obviously a machine must be properly balanced before it could make an effectual flight and hope to escape destruction.

Langley considered that he would have sufficiently succeeded in

his object if he could build a model aeroplane of reasonably large dimensions which would fly safely under its own power. To this end he now directed his efforts. He first began to construct small models propelled by rubber bands, in order that he might discover the design for a larger machine that might hope to prove itself airworthy. He made over thirty of these small models, being greatly assisted, he said, by a consideration of the tiny model aeroplane invented by the Frenchman Penaud, of which mention has already been made. Having attained promising results with these models, he proceeded to construct large machines capable of carrying a small engine. After much difficulty and many failures he produced a model 'aerodrome' (as he always called his machines, using the term 'aeroplane' in the sense of a single plane or aerofoil, as it is now styled) fitted with a light steam engine that in 1896 made a succession of good flights, one of which, over the Potomac river, exceeded three-quarters of a mile from start to finish. It is significant, in view of what happened later, to notice that one of Langley's chief difficulties lay in devising a method of successfully launching these model 'aerodromes'.

Professor Langley, already far advanced in years, considered that his object had been attained. He had demonstrated beyond question that a heavier-than-air power-driven machine was theoretically and practically capable of flight. It may be said that Stringfellow had already done this many years before, but the flights of his model had been brief and uncertain and at that distance of time could hardly be regarded as conclusive. It was impossible to deny or disregard the capabilities of Langley's aerodromes.

Langley himself had no desire to fly; the air did not lure him as it had lured Lilienthal and Pilcher and even Ader. His interest in aeronautics was, one may say, intellectual and scientific. He was satisfied with having proved that flight was possible, and was willing to leave its achievement to younger men who might take up the work where he had left it. He was not, however, permitted to abandon his labours yet.

The success of his model 'aerodrome' in 1896 had attracted the attention and awakened the interest of the United States War Department, and finally at their request, backed up by the persuasion of President McKinley, he agreed to attempt the construction of a full-sized flying-machine capable of carrying a man.

Langley realized that the main obstacle to be overcome would be the provision of a suitable engine; steam power, he felt, would be inadequate and unreliable. He consequently turned his attention to the internal combustion engine which by this time had attained to a fair degree of efficiency. No existing type, however, gave promise of satisfactory results, and no manufacturing firm could be prevailed upon to experiment with a design which they considered impracticable and for an object in which they had no faith. Accordingly Langley and his chief assistant, Charles M. Manly, set to work to design and build for themselves an internal combustion engine which should be capable of fulfilling their requirements.

From 1898 to 1903 Langley worked at the design and construction of a full-sized 'aerodrome', while Manly struggled to produce an adequate aero-engine. At length, after great difficulties had been overcome, the machine and the engine were ready and preparations made for the first trial. Langley described this aerodrome as 'built of steel, weighing completely about 730 lb., supported by 1,040 ft. of sustaining surface, having two propellers driven by a gas engine developing continuously over fifty horse-power'. This machine was afterwards reconstructed, with some modifications of design, and successfully flown in 1914 by G. H. Curtiss at Hammondsport, U.S.A., with its original engine.

The trials in 1903 can best be described by quoting extracts from the official report of the representative of the War Department, Major M. M. Macomb

'On the 17th October last everything was in readiness, and I witnessed the attempted trial on that day at Widewater, Va., on the Potomac. The engine worked well and the machine was launched at about 12.15 p.m. The trial was unsuccessful because the front guy-post caught in its support

on the launching-car and was not released in time to give free flight, as was intended, but, on the contrary, caused the front of the machine to be dragged downwards, bending the guy-post and making the machine plunge into the water about 50 yds. in front of the house-boat. The machine was subsequently recovered and brought back to the house-boat. The engine was uninjured and the frame only slightly damaged, but the four wings and rudder were practically destroyed by the first plunge and subsequent towing back to the boat-house. . . .'

'On the 8th December last, between 4 and 5 p.m., another attempt at a trial was made, this time at the junction of the Anacostia with the Potomac, just below Washington Barracks. . . .'

'The launching-car was released at 4.45 p.m., being pointed up the Anacostia towards the Navy Yard. . . . The car was set in motion and the propellers revolved rapidly, the engine working perfectly, but there was something wrong with the launching. The near guy-post seemed to drag, bringing the rudder down on the launching ways, and a crashing, rending sound, followed by the collapse of the near wings, showed that the machine had been wrecked in the launching, just how, it was impossible for me to see. The fact remains that the near wings and the rudder were wrecked before the machine was free of the ways. Their collapse deprived the machine of its support in the rear, and it consequently reared up in front under the action of the motor, assumed a vertical position, and then toppled over to the rear, falling into the water a few feet in front of the boat.'

Thus the second and final trial ended in disaster almost before it was begun, indeed before the 'aerodrome' had any chance of demonstrating whether it was capable of flight. While recovering the machine from the river further damage was inflicted upon it, and it was clear that a long period would have to elapse before any further test could be made. Eventually the War Department intimated that they could not make any additional grant of money and Langley abandoned the project.

The engineer, Charles Manly, who on each occasion had undertaken to act as pilot, escaped the disaster without any serious injury.

It is as a maker of aeronautical science that Professor Langley

gains a place among the greatest of the pioneers. His work in that field was brilliant and of enduring value and marks the beginning of exact aerodynamic science. He laid a solid foundation upon which others could build. The 'aerodrome' that he constructed and which was wrecked in the launching on the Potomac may have been an airworthy machine and, if so, Langley missed full success by a very narrow margin. In a sense it was only an accident that prevented Langley and Manly from forestalling the Wright brothers, but it was an accident that their method made all too likely. To build an aeroplane is one thing; to fly it successfully is another. At the present day, when the steadier types of aeroplanes may almost be said to fly themselves, no one would think of allowing a man who had never even been in the air to attempt to take off, fly and land a machine himself, however great a technical expert he might be. Such an action would be fraught with the gravest danger. Yet this in effect is what Manly attempted, on an experimental machine whose capacities had never been tested in the air, the only place where ultimately the qualities on any flying-machine can prove themselves. Considerations of this kind allow us to realize how the period of actual failure might have been prolonged even when aeronautical science was capable of producing an airworthy machine, had it not been for the great gliders, who were determined first of all to learn how to fly. They enable us also to appreciate the courage of men like Ader and Manly who unhesitatingly faced death in their efforts to conquer the air.

Langley's last and unsuccessful trial took place on the 8th December 1903, when the most promising attempt to fly a power-driven heavier-than-air machine ended in disaster.

The end of the long struggle was in sight, however, for by this time Wilbur and Orville Wright were already completing the preparations for their famous trial with a power-driven machine that was destined to mark the beginning of the era of true heavier-than-air flight.

VII

Wilbur and Orville Wright

§ 1

THE story of Wilbur and Orville Wright's determined struggle to solve the problems of heavier-than-air flight is a story of splendid endeavour rewarded by splendid success. Theirs was certainly one of the greatest attainments of this or any preceding age; a triumph that was gained by the exercise of those qualities of brain and heart that in the material sphere have raised mankind to the predominating position it occupies on this planet. Properly understood and appreciated, it is a story that should kindle the imagination to as fine an elation as any tale of heroic exploits of remoter days. The fullness of the triumph does not belong to the Wrights alone; it is shared by all those adventurers who through hundreds of years had sought to bring the regions of the air within the ambit of man's activity, and may be shared by any who have the ambition to enlarge the fields of this conquest. But the long romance of endeavour culminated in the work of the Wrights, and theirs was the decisive victory. Moreover, the combination of qualities which the brothers brought to bear upon their task included all those that throughout had made progress possible and were essential for ultimate success.

The era in which we live is characterized by its great scientific inventions, whereby man has so vastly increased his control over his surroundings and has been enabled to divert the hidden forces of nature to his own peculiar purposes. The harnessing of steam and electric power, and the liberation of the enormous energy dormant in oil are the chief, though not the only examples of this activity and form the basic resources on which most of the mechanical devices of modern civilization depend. One invention made possible another, and with growing momentum the development of machinery continued and still continues apace.

The aeroplane, though it was essentially part of the same process, differs in one striking respect from the other inventions of this period, such as the steam-engine, the telephone, or the internal combustion engine, and that is in the much wider demands it made upon the inventor. These no less wonderful devices were mainly the creation of man's intelligence and ingenuity; they proceeded from the brain. It required a clever and painstaking genius to invent the electric telegraph and the gramophone, but it scarcely demanded physical courage, though in the latter instance a certain dour fortitude may have been called for during the experimental stages. High mental qualities were needed, but, generally speaking, only mental qualities. With the aeroplane this was not the case. The aeronautical scientist might explore and expound the theory of heavier-than-air flight, and might construct a machine in every way adequate and efficient. This was not enough. Man had still to dare the actual experience of flight, and this required not only stark courage, but also skill, presence of mind, and a high degree of physical alertness. The man who spoke into the first telephone ran no risk: the men who flew the first aeroplanes took their lives in their hands. The slightest error of judgement, a single false movement, might prove and unhappily all too often did prove fatal. The aeroplane in its evolution made heavy demands upon the resources not only of the mind but of the body also.

Without prejudice to Lilienthal's scientific work it may be said that he and Langley stand as representatives of the two distinct qualities required by the aeronautical pioneer. Langley was the scientist, the student of flight; Lilienthal was the man prepared to venture into the air itself. In the Wright brothers these two qualities were most happily blended and operated together in complete accord. They left nothing to chance; they were willing to dare anything. Moreover they were fired with a burning enthusiasm for the cause of flight, and at the same time were capable of taking infinite and unflagging pains over the smallest and most irksome practical detail. At one and the same time they were

cautious plodding workers, romantic visionaries, and cool headed courageous adventurers. No one could have been better equipped by nature for the task which they so determinedly set themselves to accomplish.

Wilbur and Orville Wright worked together in all their researches and experiments. Mr. Griffin Brewer, who knew them well and was closely acquainted with their methods, declared that it was impossible to say where the work of one brother ended and that of the other began. Neither deserved greater credit than the other; the merit of their success belonged equally to both, or, more truly perhaps, to the singularly effective collaboration between them. Their efforts should be considered as the outcome of one common determination.

§ 2

Wilbur Wright, the third son of Milton Wright, was born near Newcastle, Indiana, U.S.A., in 1867, and Orville was born in 1871 at Dayton, Ohio, where the Wrights were then living. They were of New England stock, one of their ancestors having emigrated from England as early as 1637. While still a boy Orville possessed himself of a primitive printing outfit and began to publish a boys' paper. Later, with an improved press he produced a weekly newspaper, *The West Side News*. Wilbur then joined him in the capacity of editor, and soon they were publishing a weekly magazine in addition, which they called *Snap Shots*. Wilbur, who had a crisp and telling literary style, contributed numerous articles on local affairs. These were the great days of the 'safety bicycle', and the brothers, apt and business-like as they always were, started the Wright Cycle Company, manufacturing a machine known as the 'Van Cleve', which won a local reputation for soundness and good workmanship. They were thus engaged when their attention was first directed to aeronautics.

It was in 1896 that a newspaper paragraph recording the death of Otto Lilienthal in Germany, and giving a brief account of his

exploits, roused their interest in flying. It is a pleasant thought that Lilienthal, who in his life had done so much for the cause of flight, should by his death have inspired with something of his own ardour the two young men who were destined to take up the work to which his life had been devoted and bring it to fulfilment. The incident of Lilienthal's death seems to have made a deep impression upon Wilbur, and he was moved to re-read one of his favourite books, Marey's *Animal Mechanism*. 'From this I was led', he later declared in a lecture, 'to read more modern works, and as my brother soon became equally interested with myself, we soon passed from the reading to the thinking, and finally to the working stage.'

They read all the existing aeronautical literature that they could lay hold upon; the writings that most encouraged them were those of Lilienthal and Langley, and from them they were soon able to estimate the stage of progress that aeronautical science and practice had actually reached. They were also influenced by the work of Stringfellow, whose designs they regarded as valuable contributions to the development of the aeroplane.

From the writings and lectures of Wilbur Wright it is possible to follow the progress of their work without difficulty. One cannot do better than quote Wilbur's own account whenever their actual activities need to be recorded, and the matter is pertinent to the subject of this chapter. From the very outset the brothers realized that all the pioneers had been handicapped, in varying degrees, by one thing, namely, lack of experience in handling a machine in the air. Lilienthal's death had been due to this very cause.

'It seemed to us', Wilbur stated in the lecture already mentioned, 'that the main reason why the problem had remained so long unsolved was that no one had been able to obtain any adequate practice. We figured that Lilienthal in about five years of time had spent about five hours of actual gliding through the air. The wonder was not that he had accomplished so little, but that he had accomplished so much. It would not be considered at all safe for a bicycle rider to attempt to ride through a crowded city street after only five hours' practice, spread out in bits of ten seconds each

over a period of five years; yet Lilienthal with this brief practice was remarkably successful in meeting the fluctuations and eddies of wind gusts. We thought that if some method could be found by which it would be possible to practise by the hour instead of by the second there would be the hope of advancing the solution of a very difficult problem. It seemed feasible to do this by building a machine which would be sustained at a speed of eighteen miles per hour, and then finding a locality where winds of this kind were common.'

The Wrights, therefore, after their preliminary study of aeronautical literature, during which time they were, so to say, surveying the problem from a distance and meditating how best to approach it, decided that the first thing to do was to build a glider. They condemned as 'wasteful and extravagant' any method which included the construction of a machine before one knew how to fly it, 'mounting delicate and costly machinery on wings which no one knew how to manage'. Their decision could not have been such a simple one as it now appears. In 1896 Lilienthal had been killed, and Chanute, after limited successes, had abandoned his experiments: in the following year Percy Pilcher met his death in England. Gliding, in the face of such events, was not the kind of hobby to which one would lightly turn: how much more reasonable, if one must dabble in aeronautical research, to confine one's activities to the experimental shop and the construction of model machines. Such considerations did not appeal to the Wrights. For some little time they studied the flight of birds, hoping to gather some suggestion of the means by which they secured their balance. They came to the conclusion that this was done instinctively; the result of inherited aptitude and constant practice. So too it must be, in part, if men were to fly, they concluded.

'Now, there are only two ways of learning to ride a fractious horse', wrote Wilbur Wright with caustic humour, 'one is to get on him and learn by actual practice how each motion and trick may best be met; the other is to sit on a fence and watch the beast awhile and then retire to the house and at leisure figure out the best way of overcoming his jumps and

kicks. The latter system is the safer, but the former, on the whole, turns out the larger proportion of good riders. It is very much the same in learning to ride a flying-machine ; if you are looking for perfect safety you will do well to sit on a fence and watch the birds, but if you really wish to learn you must mount a machine and become acquainted with its tricks by actual trial. The balancing of a gliding or flying-machine is very simple in theory. It merely consists in causing the centre of pressure to coincide with the centre of gravity.'

With the admirable clarity of mind that characterized them the Wrights summed up the situation as it was when they began their experiments.

'The difficulties', wrote Wilbur, 'which obstruct the pathway to success in flying-machine construction are of three general classes: (1) Those which relate to the construction of the sustaining wings ; (2) those which relate to the generation and application of the power required to drive the machine through the air ; (3) those relating to the balancing and steering of the machine after it is actually in flight. Of these difficulties two are already to a certain extent solved. Men already know how to construct wings, or aeroplanes, which, when driven through the air at sufficient speed, will not only sustain the weight of the wings themselves, but also that of the engine and the engineer as well. Men also know how to build engines and screws of sufficient lightness and power to drive the planes at sustaining speed. Inability to balance and steer still confronts students of the flying problem. . . . When this one feature has been worked out, the age of flying-machines will have arrived, for all other difficulties are of minor importance.'

The work of the brothers falls fairly distinctly into two periods. To 1901 their primary object was to obtain experience in the air by means of gliding flights: in the construction of these first gliding machines they relied for the most part upon such aerodynamic 'data' as already existed, modifying their machines only in detail when the results of their practical experiments suggested it. After 1901, convinced that far more accurate information was needed, they carried out detailed researches for themselves, constructed gliders of more original design, turned their attention to

the production of a suitable engine, and were definitely aiming at free power-driven flight. The record of their work during this latter period becomes more scanty. Doubtless they were too busy to write or talk much, and though they made no attempt at secrecy, their work was now become far more individual in character, and presumably they shrank from anything in the nature of self-advertisement until their hopes were definitely realized and they could shew results which admitted of no doubts or arguments. Like Langley, they knew that the only way in which flight could be proved possible was by making a machine that not only could but actually did fly.

Their first glider was modelled upon Chanute's later biplane type, with a few minor alterations suggested by their own studies. They had come to the conclusion that Lilienthal's method of obtaining balance by shifting the position of the pilot's body when required was unsatisfactory and dangerous. Chanute's plan of securing the greatest possible degree of inherent stability reinforced by adjustable parts, which could be controlled by the operator in flight, appeared to promise better results. They had originally planned to provide the gliders with a supporting surface of 200 sq. ft., but the inability to obtain enough suitable material finally compelled them to reduce it to 165 sq. ft., which according to Lilienthal's calculations would be sufficient to support the machine in a wind of about twenty-one miles per hour at an angle of three degrees.

As the result of information provided by the Weather Bureau at Washington they decided to carry out their first experiments at Kitty Hawk, near the Atlantic coast of North Carolina, where steady winds favourable to gliding might be expected. They pitched their camp in the summer of 1900. The death of Pilcher, following that of Lilienthal, led them to think that the dangers of gliding made it an unreliable method of experiment, and they attempted at first to attach a line to their machine and fly it as a kite. The results showed them that some of their expectations, based on Lilienthal's figures, could not be realized, but in the main

this system proved inadequate, and they decided that actual gliding flights must be undertaken if real progress was to be made. They moved a distance of four miles to the Kill Devil Sand hills and there began to practise short gliding flights without mishap.

They proceeded at first with extreme caution, making their glides as near the ground as possible, and doing everything to eliminate unnecessary risk. They knew that they must learn to walk before they could run ; and they knew, moreover, quite apart from the natural instinct of self-preservation, that the security of their lives was the prime essential to the success of their project. The unavoidable risks of their enterprise were sufficiently grave; to have neglected any precaution, whether out of carelessness or foolish bravado, would have seemed to them the essence of inefficient workmanship. The foremost necessity was that they should retain their lives for the continuance of the task.

Wilbur Wright has given an account of this first year's practical work.

'The slope of the hills was 9·5 degrees, or a drop of one foot in six. We found that after attaining a speed of about twenty-five to thirty miles with reference to the wind, or ten to fifteen miles over the ground, the machine not only glided parallel to the slope of the hill, but greatly increased its speed, thus indicating its ability to glide on a somewhat less angle than 9·5 degrees, when we should feel it safe to rise higher from the surface. The control of the machine proved even better than we had dared to expect, responding quickly to the slightest motion of the rudder. With these gliders our experiments for the year 1900 closed. Although the hours of practice we had hoped to obtain finally dwindled down to about two minutes, we were very much pleased with the general results of the trip, for, setting out as we did with almost revolutionary theories on many points and an entirely untried form of machine, we considered it quite a point to be able to return without having our pet theories completely knocked on the head by the hard logic of experience, and our own brains dashed out into the bargain. Everything seemed to us to confirm the correctness of our original opinion : (1) That practice is the key to flying; (2) that it is practicable to assume the horizontal position—in their

gliding flights the Wrights lay in a position horizontal to the ground, in order to lessen the direct wind resistance; (3) that a smaller surface set at a negative angle in front of the main bearing surfaces, or wings, will largely counteract the effect of the fore and aft travel of the centre of pressure; (4) that steering up and down can be attained with a rudder without moving the position of the operator's body; (5) that twisting the wings so as to present their ends to the wind at different angles is a more prompt and efficient way of maintaining lateral equilibrium than shifting the body of the operator.'

The chief points in which this 1900 glider had differed from Chanute's biplane were in the absence of a vertical rudder in the rear and the employment of a 'horizontal rudder' in front of the machine. This innovation was to prove very useful in securing fore and aft balance, lack of which, in certain circumstances, had been a weakness in Lilienthal's gliders. The brothers spent the following winter considering the results of the first year's experiments and making plans for the summer of 1901. They decided to construct a new glider on the same lines as their first, but having a wing surface of 308 sq. ft. Returning to Kitty Hawk in July they proceeded to test the new machine.

The first results were unsatisfactory, but by altering the position of the pilot's seat, or perch, they were enabled to make a glide of about 300 ft. Longitudinal balance, however, was maintained only with difficulty by making great play with the front rudder or elevator. Finally considerable alterations had to be made in order to reduce the depth of 'curvature' originally allowed; after this they made numerous successful glides, the machine being easy to control even in comparatively strong winds.

During this period the Wrights had the assistance and advice of Chanute, who visited their camp and watched their experiments, giving them every encouragement when he discovered that they were interested in flying as a sport and not with expectation of making money out of it. It was in the September of 1901 that Wilbur Wright gave his lecture before the Western Society of

Engineers, from which extracts have been given. His general impression at this time seems to have been that, while they had achieved considerable practical success, the calculations of previous experimenters, on which they had so far been content in the main to rely, were often inaccurate and could not in practice be depended upon to give the desired results. As Wilbur later said:

> 'Having set out with absolute faith in the existing scientific data, we were driven to doubt one thing after another, till finally, after two years of experiments we cast it all aside and decided to rely entirely on our own investigations. Truth and error were everywhere so intimately mixed as to be indistinguishable. . . . We had taken up aeronautics as a sport. We reluctantly entered upon the scientific side of it.'

At that time they ventured the opinion that man would ultimately learn to fly, but that it would not be in their generation.

While they may not have felt justified in making a more optimistic prediction, there can be little doubt that the Wrights secretly entertained higher hopes. From this time they directed all their energies to the problem which before they had treated as an exciting hobby. During the winter they carried out exhaustive researches with the purpose of building up a structure of aerodynamic 'data' on which they could absolutely rely. They made a wind tunnel and tested hundreds of forms of wing surface, carefully and methodically recording every result. The statistical tables thus prepared were both more varied and more accurate than those previously made by Lilienthal and Langley, and they used them in all their future constructional work. These researches lasted nearly a year, at the end of which time they had built a third glider, destined to be the parent of the first successful power-driven aeroplane.

The use of an horizontal elevator in the front of the machine had already done much to solve the problem of fore and aft balance. The difficulty of securing lateral stability was still to be overcome. Their new glider, designed in accordance with the knowledge gained from their recent experiments, was altogether a far more

efficient machine than those of the years 1900 and 1901. In an attempt to obtain lateral balance they fitted a fixed vertical tail. With this glider they returned once more to Kitty Hawk in the Autumn of 1902. The early trials were disappointing. The attempt to control the balance of the machine by means of adjustable wing edges had already proved inadequate. The fixed vertical rudder, or tail, which they had hoped would remedy the defects, served only to aggravate them by making it next to impossible to counteract any sideways tilt which might develop in the course of a flight. At length they conceived the plan of making the rear vertical rudder adjustable instead of fixed. This proved to be the long-sought solution to the problem. Adequate lateral balance was obtained, but the demands made upon the pilot during flight were increased, for he had three sets of controls to manage—those working the front horizontal elevator, those maintaining the adjustments of the wing edges, and the new arrangement for adjusting the vertical rudder. Eventually they ‘ decided to attach the wires controlling the vertical tail to the wires warping the wings, so that the operator, instead of having to control three things at once, would have to attend only to the forward horizontal rudder and the wing warping mechanism ; and only the latter would be needed for controlling lateral balance ’.

The glider, thus improved, was found to be remarkably amenable to management.

‘ With this apparatus ’, said Wilbur Wright, ‘ we made nearly 700 glides in the two or three weeks following. We flew it in calms and we flew it in winds as high as 35 miles an hour. We steered it to right and left, and performed all the evolutions necessary for flight. This was the first time in the history of the world that a movable vertical tail had been used in controlling the direction or the balance of a flying-machine. It was also the first time that a movable vertical tail had been used in combination with wings adjustable to different angles of incidence, in controlling the balance and direction of an aeroplane. We were the first to functionally employ a movable vertical tail in a flying-aeroplane. We were the first to employ

wings adjustable to respectively different angles of incidence in a flying-aeroplane. We were the first to use the two in combination.'

At a much later period the Wrights, in order to protect their patent rights, were compelled to prove these claims, and they were in substance upheld in the law courts of America, England, and many continental countries.

The Wrights had now devised a flying-machine which was capable of flight and amenable to control. All that remained was to supply it with an adequate motive power. In comparison with what they had already done, this was a simple task. They turned to it, nevertheless, with the same zest and thoroughness that had characterized their previous work. Before describing the final stage of their efforts, however, it may be well to give a brief description of the 1902 glider to which they were prepared to pin their faith in the attempt to attain sustained power-driven flight.

It was a biplane, the two main wings being 32 ft. in frontal width (span) and 5 ft. in depth (chord), giving a total supporting surface of about 305 sq. ft. The pilot lay horizontally across the middle of the lower plane. The so-called 'horizontal rudder' in front had a sustaining area of 15 sq. ft. and the rear vertical rudder had an area of 6 sq. ft. Skids were used as an undercarriage to support the weight of the machine on the ground. The weight of the machine itself, without the pilot, was 116½ lb. The manner in which the machine was controlled by adjustable parts has already been described.

It took the brothers rather more than twelve months to build a suitable engine and devise an efficient screw propeller by means of which its power could be made to react on the air. As Langley had discovered, no suitable engine was yet in existence. The efficiency of the internal combustion engine had been steadily growing during the latter half of the nineteenth century, and during its last decade, chiefly as the result of the work of Daimler, who since 1882 had been perfecting a light petrol engine for use in the motor-car, was beginning to assume something like its present

form. It was still far too heavy, however, to be applied to aircraft. The Wrights realized that the weight per horse-power developed must be drastically reduced, whilst the strength and reliability must be retained. At the present day it is not utterly impossible to find large engineering firms with a big capital, stimulated by trade competition, who may be willing to experiment with strange and unfamiliar designs. In 1902 this was quite impossible. There were no wealthy firms engaged in producing internal combustion engines by the thousand, to whom experiment was part of the day's work. Moreover, it was an article of the engineer's faith that weight and reliability could not be divorced, and engineers do not readily abandon their cherished beliefs. Another difficulty lay in the fact that existing factory plant was far more limited and unadaptable than it is to-day. Like Langley and earlier pioneers, the Wrights were compelled to design and construct their own engine.

The fact that in a year they succeeded in designing and constructing an engine giving thirty horse-power and weighing only 7 lb. per horse-power was in itself an accomplishment that might secure them a degree of fame. Indeed, their work in this connexion—like the equally meritorious achievement of Langley's assistant, Charles Manly—constitutes an engineering feat that only the more momentous success it made possible could have dwarfed to comparative insignificance. The difficulties involved in designing a suitable screw propeller might have confounded less resourceful and determined men.

At last, towards the end of 1903, all was ready. A new machine had been built similar to the successful one of the previous year. As they found that their engine developed more power than they had anticipated, they utilized the extra weight allowed them in strengthening the general structure. Once more they visited Kitty Hawk and fitted the engine to the new machine. After a few practice flights on the old glider they prepared for the great test. A general invitation to be present at the trial was extended to the inhabitants of the district, but few responded. 'Not many

were willing to face the rigours of a cold December wind in order to see, as they no doubt thought, another flying-machine *not* fly.' Five gentlemen turned up to witness the conquest of the air. They were Mr. A. D. Etheridge, Mr. W. S. Dough, Mr. W. C. Brinkley, Mr. John Ward, and Mr. John T. Daniels. Little would they think, as they came to the level ground north of the Kill Devil Hill, impelled probably more by casual curiosity or friendliness towards the young inventors than by any real interest in aeronautics, what an epoch-making event they were to see. For a truly epoch-making event was about to take place. Sir Walter Raleigh, in the first volume of *The War in the Air*, quotes the description of this famous morning written by Orville Wright for the Aeronautical Society of Great Britain. It is a concise and unadorned narrative.

'On the morning of 17th December, between the hours of 10.30 o'clock and noon, four flights were made, two by Mr. Orville Wright, and two by Mr. Wilbur Wright. The starts were all made from a point on the levels, and about 200 ft. west of our camp, which is located about a quarter of a mile north of the Kill Devil Sand Hill, in Dare County, North Carolina. The wind at the time of the flights had a velocity of twenty-seven miles an hour at 10 o'clock and twenty-four miles an hour at noon, as recorded by the anemometer at the Kitty Hawk weather bureau station. This anemometer is 30 ft. from the ground. Our own measurements, made with a hand-anemometer at a height of 4 ft. from the ground, showed a velocity of about 22 miles when the first flight was made and 20½ miles at the time of the last one. The flights were directly against the wind. Each time the machine started from the level ground by its own power alone, with no assistance from gravity or any other sources whatever. After a run of about 40 ft. along a mono-rail track, which held the machine 8 inches from the ground, it rose from the track and under the direction of the operator, climbed upward on an inclined course till a height of 8 or 10 ft. from the ground was reached, after which the course was kept as near horizontal as the wind gusts and the limited skill of the operator would permit. Into the teeth of a December gale the *Flier* made its way forward with a speed of 10 miles an hour over the ground, and 30 to 35 miles an hour through the air. It had previously been decided that, for reasons of personal safety,

these first trials should be made as close to the ground as possible. The height chosen was scarcely sufficient for manœuvring in so gusty a wind and with no previous acquaintance with the conduct of the machine and its controlling mechanisms. Consequently the first flight was short. The succeeding flights rapidly increased in length, and at the fourth trial a flight of 59 seconds was made, in which time the machine flew a little more than half-a-mile through the air and a distance of 852 ft. over the ground. The landing was due to a slight error of judgement on the part of the operator. After passing over a little hummock of sand, in attempting to bring the machine down to the desired height the operator turned the rudder too far, and the machine turned downwards more quickly than had been expected. The reverse movement of the rudder was a fraction of a second too late to prevent the machine from touching the ground and thus ending the flight. The whole occurrence occupied little, if any, more than one second of time.

'Only those who are acquainted with practical aeronautics can appreciate the difficulties of attempting the first trials of a flying-machine in a 25 mile gale. As winter was already well set in we should have postponed our trial to a more favourable season, but for the fact that we were determined, before returning home, to know whether the machine possessed sufficient power to fly, sufficient strength to withstand the shocks of landings, and sufficient capacity of control to make flight safe in boisterous winds, as well as in calm air. When these points had been definitely established we at once packed our goods and returned home, knowing that the age of the flying-machine had come at last.'

Wilbur Wright, writing in the *Century Magazine* in 1908, accurately describes the first of the four flights, that lasted twelve seconds, as 'the first in the history of the world in which a machine carrying a man had raised itself into the air by its own power in free flight, had sailed forward on a level course without reduction of speed, and had finally landed without being wrecked'.

Thus at last man had learned to fly. The hopes of many faithful workers were rewarded, not as it had so often seemed, with failure, but with success. The beginnings, it is true, were modest and not very spectacular, like the first uncertain flight of a nestling,

but they were the certain beginnings of a mighty conquest, the full meaning and extent of which one can even now only dimly imagine. Man had added one more to the long tale of his triumphs over his natural surroundings.

§ 3

Here, with the successful flights of the Wright brothers' first power-driven aeroplane, the story of the evolution of heavier-than-air flying-machines might properly end. Aeroplanes of to-day, though their capacities for flight are so enormously increased, are still surprisingly similar to the Wrights' machine of 1903. Experience has enabled great improvements to be made in details of design, and in methods of construction, but still it remains true to say that the great achievements of the aeroplane have been due far more to the development of the aero-engine than to the advance of aerodynamic science, considerable as that has been. The aeroplane of the present day is definitely the machine the Wrights invented, vastly improved in structure and design and fitted with engines so powerful that the thirty horse-power engine of the Wrights seems like a toy beside them.

The contributions of Wilbur and Orville Wright to the progress of flying do not end, however, with the invention of the first aeroplane. For many years they led the way in developing the efficiency of heavier-than-air machines, and did more than any of their contemporaries in compelling a sceptical and indifferent world to accept them at their true value. Looking back over the events of the past years we undoubtedly tend to attach a deeper significance to the happenings at Kitty Hawk on the morning of the 17th December 1903 than could have been felt at the time. It is doubtful whether the five gentlemen who witnessed these first flights were as impressed as we might suppose them to have been. If one had said to the Wrights after their return to Dayton, 'Well, you have built an aeroplane that will fly; when do you think it may be expected to serve any useful purpose? How long, for

instance, do you imagine it will be before an aeroplane will make a non-stop flight across the Atlantic ?' they might have answered, full of optimism, 'It *may* be done within the present century; it will certainly be done sometime.'

Actually the achievement of 1903 attracted no notice at the time. The Wrights proceeded quietly and confidently with their task of improving their first machine unembarrassed by either applause for what they had already accomplished or interest in what they hoped to accomplish in the near future.

Having built a new machine, somewhat heavier and more strongly constructed than their first power-driven aeroplane, the brothers continued their experiments in 1904, on what was known as Huffman's Prairie, Simms Station, eight miles distant from Dayton. They invited representatives of the press to be present at their first trials, but owing to lack of a sufficiently strong wind and some temporary defect in the engine the attempts at flight were unsuccessful. Next day they were similarly unsuccessful and popular interest in their activities waned rapidly. After a time the defect in the engine was remedied and the brothers began to resume their flights.

During 1904 and 1905 the Wrights were chiefly occupied in improving the stability of their machine, which in certain circumstances was found to be still unsatisfactory. Towards the end of 1905 they had succeeded in their efforts with highly encouraging results. In November 1905 Orville Wright described their success in a letter written to the Aeronautical Society of Great Britain.[1]

'During the month of September we gradually improved in our practice, and on the 26th made a flight of a little over 11 miles. On the 30th we increased this to $12\frac{1}{5}$ miles, on October 3rd to $15\frac{1}{2}$ miles, on October 4th to $20\frac{3}{4}$ miles, and on the 5th to $24\frac{1}{4}$ miles. All these flights were made at about 38 miles an hour, the flight of the 5th occupying 30 minutes 3 seconds. . . . We had intended to place the record above the hour, but the attention these flights were beginning to attract compelled us

[1] Quoted by Sir Walter Raleigh, *War in the Air*, vol. i.

suddenly to discontinue our experiments in order to prevent the construction of the machine from becoming public.'

'The machine passed through all these flights without the slightest damage. In each of these flights we returned frequently to the starting-point, passing high over the heads of the spectators.'

During this time the Wrights had worked without any special efforts at concealment, remaining content so long as their experiments were not embarrassed by the presence of crowds. The field in which their flights took place was open to public view and electric cars passed it every half-hour. The brothers merely stipulated that no photographs be taken and no sensational reports published. Public indifference at first protected them effectively enough, but at length rumours of their achievements began to spread, and the Wrights, satisfied that their aeroplane could now be regarded as having successfully passed the experimental stage and proved its efficiency in the air, withdrew from the public view and occupied themselves with the securing of patent rights. Heavier-than-air flight was now an accomplished fact and a new era in the history of transport was about to begin. The world at large, however, especially as represented by the governments of the great nations, was hardly as yet prepared to recognize it. How the later efforts of the Wright brothers helped to overcome this inertia of scepticism will be shortly referred to in the concluding chapter.

VIII

The Evolution of the Airship

§ 1

WHILE the aeroplane was being gradually developed from Cayley's statement of its theoretical principle to the first power-driven machine of the Wrights, other aeronautical pioneers were endeavouring to accomplish controlled flight by means of lighter-than-air machines. Apart from their common aspirations to navigate the

air and in a certain degree their common dependence upon the new sources of mechanical power, there was little connexion between the men interested in heavier-than-air flight and those who were seeking to produce a navigable balloon. Their efforts were based on entirely different principles and their problems were for the most part quite dissimilar. Thus there could be no point in interrupting the account of the aeroplane's slow but continuous development in order to insert descriptions of the early dirigibles in a strictly chronological sequence. Practically speaking, the two movements were independent of one another and unrelated. The story of each can best be told separately.

It is not intended here to give a detailed account of the evolution of the dirigible airship. This must not be held to imply any disparagement of the principle or the potentialities of lighter-than-air machines. The reasons are, firstly that the story of the early airships is in itself a simple one to tell, and secondly that the main interest in their development is of a technical sort. The difficulties to be overcome were many and great, but they were not obscure in their main features ; chiefly they were difficulties of construction, apart of course from the vital need for an adequate power of propulsion. The free balloon existed ; it could rise in the air and remain aloft for a reasonably long period : could it be made to travel through the air in any desired direction instead of remaining passively at the mercy of the winds ? Given an independent motive power this at once became a reasonable possibility. This motive power became available during the nineteenth century. All that then remained was to construct a balloon capable of being controlled and strong enough to withstand the strains and stresses that it would encounter in its passage through the air. The story of how this was eventually accomplished is a record of persistence, courage, and mechanical and engineering skill, but described in sufficient detail to make it coherent it must contain lists of dimensions and calculations likely to weary the non-technical reader and possibly leave him but little the wiser in the end.

Furthermore the history of the evolution of the dirigible airship from the free balloon has no dramatic culmination such as is marked by the flight of the Wright's first power-driven aeroplane. One cannot describe the occasion when the air was first decisively conquered by a lighter-than-air craft, and in any case the success was less spectacular and appealed less to the imagination. In the first decade of the twentieth century, even more than to-day, it seemed a wonderful and bewildering thing that an aeroplane, a machine of metal and wood, carrying a man, should rise in the air and fly like a bird. It was in the nature of a miracle. On the other hand the balloon had long ago come to be taken for granted; every schoolboy knew why a balloon rose in the air, and to fit it with an engine and alter its shape, so that it could be steered freely at will, was a development that all could readily understand. It might be a supremely difficult feat, but it lacked that sense of the mysterious, of the seemingly impossible made possible, that no one could help but feel in some degree when he first saw an aeroplane in flight. Thus inevitably the story of the dirigible airship is less impressive, less dramatic than the story of the aeroplane. It can perhaps only be appreciated fully by those who are able to understand the nature of the mechanical and engineering accomplishments that it entailed.

No sooner had the free balloon made its appearance in the latter part of the eighteenth century than efforts were made to direct it. People who regarded the balloon as a serious and practical invention readily perceived that if it were to serve any really useful purpose it must be brought under control. The first and perhaps natural hope, that balloons might be propelled by sails in the same way as ships, was soon shown to be impossible; since the balloon and its sails moved in the same single element the sails could offer no independent resistance to the wind, but hung limp and passive as the balloon floated with the breeze. The idea of using oars was theoretically more promising, but the lack at that time of

any motive power more effective than muscular energy deprived the plan of any hope of practical success. However, numerous attempts were made in the early days of ballooning to secure some sort of control over its movements.

Blanchard, the most famous of the early aeronauts, made attempts to steer a balloon by means of aerial oars and a rudder in 1784, but they naturally proved ineffective. Two scientists, the Abbés Miollan and Janinet, thought of an ingenious device for propelling a balloon by allowing the hot air (they intended to use a Montgolfière) to escape from a hole at one end of the bag with, they hoped, sufficient reaction to drive them forward. A public demonstration was announced, but difficulties delayed the start, and the crowd, with the unreasoning impatience and selfishness that seems so easily to take possession of masses of people assembled to witness a spectacle provided by others, became infuriated and completely destroyed the balloon. It is noticeable that the early balloonists had almost as much to fear from the people they were endeavouring to entertain and impress as from the natural hazards of their enterprise.

A little later the Robert brothers made a serious attempt to navigate a balloon with the help of oars. The bag containing the hydrogen was melon-shaped, and a long car, brightly decorated, was suspended beneath it. A silken rudder was attached, and sailors were hired to ply six silken oars. On one journey, in a very light breeze, they did succeed in describing a slight curve, tacking some 22° away from the direct course of the wind. The Roberts were also the first who actually introduced an air bag inside the gas bag for the purpose of controlling the internal pressure of the balloon. Eventually, during a voyage with the Duc de Chartres, who had interested himself in the enterprise, they were struck by a violent gust of wind and only escaped with their lives as a result of the Duke's action in slashing open the balloon with his sword.

An interesting suggestion, though it was not put into practice till a much later period, was made by a Mr. Francis Hopkinson, of

Philadelphia, who proposed that a balloon might be driven through the air by a propeller set in the stern. It should be remembered that this idea of the screw propeller had not at that period even been applied to ships.

By far the most able plan made for a dirigible balloon at this time was the one designed by General Meusnier, of the French Army. He studied the problem systematically and scientifically in order to decide what would be the most suitable shape for a balloon to enable it to move easily through the air and withstand the severe pressure that it must encounter. The balloon, he decided, should be roughly egg-shaped, with a pointed car that would offer little resistance to the air. The car was to be rigidly attached to the balloon so that it should be incapable of any independent motion. The balloon was to be made in two layers, the outer one to be filled with air and the inner bag with hydrogen; this, he held, would stiffen its resistance and enable it to retain its shape under pressure. He also intended to secure balance by the addition of stabilizing planes or fins. The inevitable weakness of Meusnier's design was its lack of mechanical motive power, which he thought to supply by having eighty oarsmen to drive the airship forward. Given a suitable engine it seems likely that General Meusnier's airship would have been capable of a fair degree of controlled flight. Certainly no better attempt was made for more than fifty years, and his design proved very valuable to later inventors. Meusnier was killed in the Revolutionary wars in 1793, and no attempt was made to construct an airship in accordance with his competent design.

These initial efforts were not entirely without their value: they did at least show that to direct the course of a balloon was not a simple matter, as it may at first have appeared, but an extremely difficult one. Indeed many people quickly came to the conclusion that the task was impossible. In a sense they were right, for nothing could really be done until some sort of engine was available for supplying motive power. In one sense lighter-than-air craft, in spite of their buoyancy, are more dependent on mechanical

power than heavier-than-air, for the free glider is almost certainly capable of greater development than the free balloon. On the other hand the airship (to use the term commonly employed to describe the dirigible balloon) had advantages in that it did not demand so highly efficient or so light an engine as the aeroplane, and, moreover, was capable of obtaining a small degree of success by flying at low speed. As Wilbur Wright pointed out, one of the greatest difficulties that the power-driven aeroplane had to contend against lay in the fact that a very high degree of efficiency had to be attained before it could fly at all. Where an immature aeroplane with a feeble engine could not even lift its own weight, an equally imperfect airship might accomplish a short flight of a few miles an hour against a gentle breeze and from that progress gradually towards fuller efficiency. This was the chief reason why a certain degree of success was achieved by airships long before aeroplanes were able to make even trial flights, though once the latter had been sufficiently developed to sustain themselves in the air, they quickly outdistanced the lighter-than-air machines in their progress.

When it became apparent that attempts to propel and guide balloons by means of sails or oars worked by muscular energy were doomed to failure, hardly anything else was done until the middle of the nineteenth century. As has been previously noted, the balloon lost its early prestige and was rarely seen except at fairs and similar places of amusement. From time to time schemes for controlling balloons were put forward, but for the most part they were entirely fanciful and grotesquely impracticable, and contributed nothing to the ultimate solution of the problem.

§ 2

In 1850 a model airship, shaped like a torpedo and driven by a screw propeller worked by springs, was exhibited in the Hippodrome at Paris. It was constructed by a clever clock-maker named Julien, who had determined the shape to be employed by drawing small models through the water and noting the resistance they

offered. This ingenious device made creditable flights against the wind and was certainly a highly efficient and interesting toy. Julien had been assisted in his work on the model by another skilful engineer, Henri Giffard, who, thus drawn to the subject of aeronautics, proceeded to design and construct a full-sized dirigible balloon.

Giffard, who best deserves the title of the inventor of the dirigible airship, had already made a number of balloon ascents and experimented in the construction of light engines. In 1851 he patented a design for an elongated balloon to be propelled by a steam-engine driving a screw. He succeeded in borrowing a sum of money from friends and in the following year built an airship according to his plans. The gas-bag was shaped like a fat cigar pointed at each end and enclosed in a network of cords that were drawn down beneath the balloon and attached to a long pole. To this the car was fixed, and in the rear was a triangular sail to act as a rudder. The 'balloon' was 143 ft. in length and 39 ft. in diameter and his steam-engine produced one horse-power per 110 lb. of weight. Adequate and very necessary precautions were taken to guard against the danger of the engine setting fire to the inflammable gas in the balloon.

With this craft Giffard made a voyage on the 23rd September 1852. A strong wind was blowing, and he found that he could not develop sufficient power to move forward against it, but he attained a speed of some six to ten feet per second relative to the air and found that he could guide the airship without difficulty. After this he constructed other small dirigibles with which he confirmed his previous success. He realized, however, that he could not hope to attain a satisfactory speed or contend with even moderately strong winds unless he greatly increased the power of his engine, which would necessarily demand much greater lifting capacity in the balloon. Having made a large sum of money by the manufacture of small high-speed engines and his invention of the injector, he planned an immense airship which he calculated would be

capable of a speed of forty-four miles an hour. The length of the torpedo-shaped balloon was to be no less than 2,000 ft., with the other dimensions in proportion. His plan was complete, and he was preparing to begin the work of building the huge airship, but failing health compelled him to desist, and he died in 1882 with his ambitious project unattempted.

Giffard at least proved that a dirigible balloon was a practical possibility, and henceforth almost continuous attempts were made to improve on his performances. The limited achievements of these early dirigibles, together with the disasters that too frequently ended their careers, gave rise to a widespread and persistent opinion that airships would never be of any real use to mankind, but the few enthusiasts who pursued the ideal of lighter-than-air flight, like their contemporaries who were working to perfect the aeroplane, never ceased to believe that they were on the verge of complete success. This spirit of unquenchable optimism was the great driving force that inspired the aeronautical pioneers in the closing decades of the nineteenth century. Without it man would never have learned to fly.

After Giffard came Dupoy de Lome and Gaston Tissandier. They both succeeded in building dirigible balloons which proved themselves airworthy in the limited sense that they made flights in perfect safety, but the designs and the motive power employed (Dupoy actually resorted to muscular energy to drive a screw and Tissandier employed an electric motor) prevented them from improving upon Giffard's achievements, and their designs were such that no real progress could be expected from them. The shape of their balloons offered too much resistance to the air, and the cars containing the engines were suspended much too far below the gas-bag.

Captain Charles Renard, working with Captain Krebs, was the first to make a substantial advance towards an effective dirigible. Receiving a grant of money from General Gambetta, these two proceeded to construct an airship, first working out the require-

ments of the various parts of the craft in a business-like and scientific manner. They combined, as far as possible, the best characteristics to be found in previous designs. They decided upon a torpedo-shaped balloon with a blunt instead of a pointed bow, and used a very powerful electric motor to drive the screw. This machine, the celebrated *La France*, proved notably successful. In five out of seven voyages spread over a period of two years *La France*, flying steadily through the air and obedient to her controls, succeeded in traversing many miles and returning to the starting-place, on the last occasion making an average speed of 14½ miles an hour. Thus by 1885 the dirigible airship had attained a measure of proficiency that began to arouse interest in its future possibilities as an engine of war. This, naturally, proved an additional stimulus to its development.

La France was not only the most successful dirigible that had so far been built; all subsequent non-rigid airships were influenced by the main features in its design, so that Renard can claim to have solved the main difficulties presented by that type of aircraft, or at least to have indicated the manner in which they might be overcome. The electric motor-engine was perhaps the least useful part of his invention, for though it developed as much power as any preceding type, it was incapable of further development on the large scale necessary to make the airship a useful vehicle. *La France* was 165 ft. long and 27½ ft. in maximum diameter. The most striking feature of the design was the blunt and thick bow making the balloon almost whale-shaped, an arrangement that gives many advantages in flight.

France, that first produced the balloon was also, as we have seen, the nursery of the dirigible airship, the names of Meusnier, Giffard, and Renard standing pre-eminent in the early history of the non-rigid type, which was the first to attain a reasonable measure of efficiency. After the Franco-Prussian war, however, Germany began to take an interest in lighter-than-air craft. In 1872 Harlein had built a dirigible balloon which possessed several promising

features, the chief of these being the introduction of a gas-engine which was to draw its supplies of fuel from the balloon itself. This was a well-designed craft, and though it accomplished no great flights, restricted as it was by the use of coal gas, it attained a speed of 15 ft. a second near the ground. Lack of money prevented any further progress by Harlein.

Another German dirigible was built in 1879, but it failed in actual trial in 1880. Seventeen years later Wolfert, who with Baumgarten had designed the craft, made a second attempt, but the balloon caught fire and he was killed. Wolfert's airship is only noteworthy from the fact that it was to be driven by a Daimler benzine motor. In the year of this disaster, 1897, an Austrian named Schwartz designed a rigid airship, the balloon being enclosed in a thin casing of aluminium. Two machines were built, but both were quickly destroyed, one during inflation and the second at the end of a brief flight. However, the appearance of a rigid airship was a significant event, foreshadowing the achievements of Count Zeppelin, and the use of a petrol motor marked the beginning of a stage in engine development that was to have far-reaching results on the evolution of a really efficient airship.

There are three main types of dirigible airship, the non-rigid, the semi-rigid, and the rigid. In the non-rigid type the covering of the gas balloon is made of some soft flexible fabric and retains its shape as the result of the internal pressure of gas and air bags. In the rigid type the balloon has a stiff unyielding framework of light thin metal, strong enough to withstand the pressure of the air. The semi-rigid, as the name implies, is a compromise between these two types: the shape of the inflated balloon is mainly preserved by the internal pressure, but it is strengthened by some such device as a longitudinal metal keel. Through the genius of Count Zeppelin rigid airships were first developed, and one may almost say perfected, in Germany; the non-rigid type continued to be developed in France, and at a later period and with at first only limited success, in England.

At the close of the nineteenth century dirigible airships had still to prove their worth. In favourable conditions it was now possible to navigate the air in lighter-than-air machines, but their achievements so far had been tentative and in the nature of experiments only. They were still too unreliable and too limited in their activities to serve any useful purpose.

§ 3

The year 1898 is significant in the history of the dirigible airship. In this year Count Zeppelin began his career as a builder of rigid airships in Germany, and in France Santos Dumont first roused the enthusiasm of the Parisian populace by his picturesque and spectacular performances in the air. Santos Dumont, a wealthy young Brazilian with a strong mechanical bent and a craving for excitement, is in many ways one of the most remarkable personalities in the history of aeronautics. He took to flying as a sport and continued to pursue it with the eager zest and enthusiasm of a boy. He revelled in the plaudits of the crowd, but his love of display sprang more from the naïve exuberance of an emotional temperament than from any deep-rooted egotism in his nature. He reminds one somewhat of his fellow Southerner, Vincent Lunardi. Generous even to extravagance, he never sought to make money out of his exploits, and the valuable prizes that he strained every nerve to win were afterwards freely distributed in charity. His fame and popularity in France and England were tremendous, and he certainly did more than any other man to arouse popular interest and enthusiasm in the cause of flight. Even to-day his name is probably more widely familiar than that of the Wrights, and only the name of Zeppelin has impressed itself more deeply on the popular imagination, now, unhappily, in many countries with a sinister significance.

Santos Dumont, rich, of a venturesome disposition and keenly interested in mechanical devices, especially those of a novel kind, was first attracted to the new and hazardous sport of motoring and

motor cycling. Still in search of thrilling experiences he began to make balloon ascents. Finally in 1898 he decided to fit a light engine from one of his cycles to a balloon of his own design and navigate the air. His first airship was extremely small and somewhat resembled the type used by Tissandier before the era of Renard and *La France*. On its first flight, however, it proved itself obedient to control, although in descending the balloon doubled up in the middle owing to his inability to pump in sufficient air to make good the loss of volume as the gas contracted. Roused to enthusiasm by his comparative success Santos Dumont proceeded, during the next few years, to construct one airship after another with astonishing prodigality and energy. His personal good fortune never failed him: numerous disasters of a terrifying nature overtook several of his machines, but he emerged from them all unhurt, meeting his narrow escapes from death with the same carefree gaiety that he exhibited in his most successful exploits. In all he built fourteen airships of various types, some safe slow vessels in which passengers might enjoy a trip over Paris, others that promised a fair turn of speed. In 1900 the Paris Aero Club awarded him its 'Encouragement Prize', and in 1901, after several unsuccessful attempts, he won the prize offered by M. Deutch de la Meurthe for a flight from St. Cloud round the Eiffel Tower and back, a distance of nearly seven miles, to be completed within thirty minutes. In his later designs he tended to imitate the more efficient shape adopted by Renard, with satisfactory results. He continued to treat aeronautics as a sport, eventually turning his attention to heavier-than-air machines with marked success, and he never attempted to construct a large airship that could hope to compete with the giants that were now beginning to make their appearance. His career, flamboyant, vivacious, and attractive, acted like a tonic upon the generation that had witnessed so many unsuccessful enterprises and forms a pleasing interlude in the grim struggle for the conquest of the air.

While Santos Dumont had alternately enchanted and thrilled

the people of France by his picturesque achievements and hair-breadth escapes, others were making determined attempts to produce dirigible airships on a much larger and more ambitious scale. The Lebaudy brothers, rich sugar refiners, became interested in aeronautics in 1899, and appointed an engineer, Julliot, and a balloon maker named Surcouf to design plans for a large and powerful airship. In 1902, a year that saw two dreadful airship disasters in France, their first vessel, named the *Jaune*, was ready. It was a semi-rigid, the lower part of the balloon being flat and attached to a metal framework. Fish-like in shape, it measured 183 ft. in length, and was propelled by a forty horse-power Daimler petrol engine. At once it proved itself highly efficient, making twenty-nine successful voyages within a year, and only once failing to return to its starting-place. In 1904 with a new envelope the *Jaune* on one occasion travelled a distance of 62 miles in 2¾ hours, making an average speed of 22 miles an hour.

In the years that followed numerous airships of the Lebaudy type were built and taken over by the French military authorities or foreign Governments, among them being the *Lebaudy*, *La Patrie*, and *La République*. All of them performed well, though some were overtaken by disaster and destroyed. It has been said with truth that the *Lebaudy* semi-rigid airships made aerial navigation a practical reality, though they were still far from reliable in anything except very fair weather. In 1902 the *Jaune* was the most efficient flying-machine of any kind that had so far been produced, for the aeroplane was still a thing of the future and Count Zeppelin had not yet proved the worth of his great rigid dirigibles. By 1906 the airship had been definitely adopted as a war machine by the French military authorities, and soon no less than three companies existed in France for the purpose of constructing semi- and non-rigid airships for the Government and the Governments of France's diplomatic allies. A successful non-rigid airship, *La Ville de Paris*, had been built in 1907 for M. Deutch de la Meurthe, its main design being similar to Renard's *La France*, with many struc-

tural improvements that advancing knowledge and improved workshop technique had made possible. When *La Patrie* escaped from her moorings and drifted across France and Britain to vanish for ever in the Atlantic ocean, *La Ville de Paris* was at once handed over to the French Government by the patriotic owner to take its place. *La Ville* proved a steady, airworthy vessel, capable of long voyages, but her lack of engine power caused her to compare unfavourably with the later Lebaudy semi-rigids in the matter of speed. In 1909 another non-rigid of similar design, but somewhat larger, the *Clement-Bayard*, was constructed for the Russian Government.

France continued to pin her faith to the semi- and non-rigid types, but by this time Count Zeppelin had come to the fore with his huge rigid airships whose performances soon eclipsed those of any other kind of lighter-than-air vessel. Count Ferdinand von Zeppelin was a man well advanced in years before he seriously devoted his attention to aeronautics. As early as the American Civil War he had made a balloon ascent and he came into prominence during the Franco-Prussian War of 1870–1. Whether it was the unsuccessful efforts of Schwartz that first attracted his attention to the possibility of constructing large rigid airships, or whether he had long been pondering over his plans, cannot be certainly stated; in 1898 he floated a limited liability company with the object of obtaining funds for his ambitious enterprise. The first airship was built and ready for its trials in 1900. In size and power it far exceeded any airship that had so far been seen; it was planned on original and daring lines, and it is interesting to note that although Zeppelin's later vessels differed in structural details and in size, he was never called upon to modify the general conception of his first design. The first Zeppelin, like its successors, was a long, pencil-shaped craft rigidly constructed with sixteen metal girders running longitudinally, the length of the hull being subdivided into sixteen sections from bow to stern by aluminium partitions. In each of these compartments except the end ones was a separate

balloonette filled with hydrogen. The whole framework was covered with a thick fabric, with air spaces between it and the hydrogen bags. Two cars or gondolas were placed close beneath the keel of the airship, each containing a sixteen horse-power Daimler petrol motor. This first Zeppelin was 416 ft. long and weighed in all 9 tons.

After many difficulties the ship was launched from its immense floating hangar on Lake Constance on the 2nd July 1900. This voyage was not a complete success, but in the following October much better results were obtained, excellent control being established and a speed of nearly 20 miles an hour obtained. Count Zeppelin was jubilant, but he had exhausted his financial resources, and it was not until 1905 that his second airship was completed. It was slightly smaller than the first, but possessed far more powerful engines. Two trials of this airship were made, one in 1906 and the second in 1907, but bad fortune attended them both. In the second trial the airship flew for a short distance at a speed of 30 ft. a second, but was soon forced to descend and during the night was destroyed by the wind. Encouraged rather than deterred by these results, Count Zeppelin produced his third dirigible in October 1907, and its success justified all his hopes and rewarded his untiring labours. On its official trial the third Zeppelin made a voyage of 67 miles at a height of half a mile and a speed of more than 29 miles per hour. It proved eminently tractable in the air, sailing evenly and securely. The German Government, convinced at last that the rigid airship was worthy of encouragement, now came to Count Zeppelin's aid with a financial grant. The *Zeppelin IV* was then constructed, a huge airship 446 ft. long, having a total buoyancy of 16 tons. Its early trials were thoroughly satisfactory and broke all existing records for air transport. In June 1908 the vessel remained in the air for 12 hours, covering a distance of 270 miles at an average speed of 22 miles an hour, encountering much inclement weather during the voyage. When at the conclusion of another great flight the airship caught fire and

was destroyed, the German government and people liberally and enthusiastically contributed money for the construction of new and even larger dirigibles. These huge airships, so powerful and yet so graceful and beautiful in flight, seemed now to be regarded as symbols of the growing might and majesty of the German Empire, and their future development was fostered not only by the dour determination and zeal of Count Zeppelin, but by the resources of the Government and the patriotic enthusiasm of the German nation. The rigid airship had securely established its supremacy among all existing types of lighter-than-air craft.

It is, of course, impossible to say what may be the future developments of dirigible airships, but it certainly seems as though the rigid type will prove the most serviceable for long-distance transport. It is far more capable in the air, its only weakness lying in the fact that when landing a chance mishap may lead to disastrous results, which a non-rigid might possibly avoid by rapid deflation. The development of the mooring mast has recently tended to obviate this difficulty to a large degree. However, such speculations are beyond the scope of our present purpose.

It only remains to mention the work of Major von Gross and Major von Parsival, who, about the time that Zeppelin was winning his first pronounced successes, produced two non-rigid types of airship in Germany. Numbers of these Gross and Parsival non-rigids were built and performed well enough to persuade the Government to take them over. More efficient, perhaps, in details of design and structure, they did not mark any pronounced aeronautical advance beyond the stage reached by the Lebaudy semi-rigids in France.

In concluding this brief survey of the evolution of the airship, it may be stated without fear of contradiction that Count Zeppelin gave the world the first really efficient dirigible, and it is impossible to regard his aeronautical achievements with anything but admiration. The military effectiveness of the Zeppelins during the war period was comparatively slight, but the number of voyages made by them from Germany to Great Britain, in the

face of organized military opposition, proved their reliability and resourcefulness as aircraft. However much one may deplore the purposes to which they were devoted, it is impossible to deny that their achievements in the air established beyond doubt the practicability of aerial transport by lighter-than-air machines.

IX

Conclusion

§ 1

The years from 1905 to 1909 were starred with thrilling deeds and startling triumphs in the air. During this period the initiative, the persistence, and the daring of individual flying men established the supremacy of the aeroplane and consolidated the conquest of the air that the Wrights' invention had made possible. After the great flying meeting at Rheims in 1909 the world could no longer regard the aeroplane with indifference, and it became clear to all thinking men that the era of aerial transport was inevitably close at hand. It is with reluctance that one resists the temptation to describe in detail the stirring accomplishments of what was indeed the heroic age of flying; but the scope and compass of this small volume do not permit this. With the appearance of the first power-driven aeroplane capable of sustained flight and the evolution of an efficient dirigible airship the actual conquest of the air was effected: the extension of this conquest and the possibilities of increased activity that it offers to mankind form another story that is as yet only just begun. It is not for our generation to write *finis* to the history of man's exploitation of the air. A very brief summary of the events that followed the invention of the aeroplane must here suffice.

Though France contributed little to the invention of the first aeroplane, she was the first country to realize its importance and to

foster its development. Indeed, while the Wrights were carrying out their experiments at Kitty Hawk, enthusiasts in France were already attempting to produce a heavier-than-air flying-machine, and had achieved a measure of independent success when Wilbur Wright brought his aeroplane to Europe. The result was that the Wrights found an eager body of men ready to assist them in developing and exploiting their invention, and at the time the French pioneers were enormously stimulated and encouraged by becoming acquainted with the Wrights' aeroplane, the accomplishments of which so far exceeded their own tentative efforts. Thus an atmosphere was created extremely favourable to further progress; new types of machines were tried, fruitful experience was gained, and with the improvements in engine design the capabilities of the aeroplane increased by leaps and bounds.

Captain F. Ferber had initiated this latest interest in heavier-than-air machines in France; and began to experiment with gliders in 1899. Like the Wrights, he was first inspired by reading accounts of Lilienthal's work, and became a zealous convert to his belief that practice in the air was the essential element in flight. At first he had little success, but gradually made progress; he got into touch with Chanute and heard for the first time of what the Wrights were doing. Later he was joined by the brothers Voisin, M. Archdeacon, and others, and together they laboured to produce an efficient aeroplane.

While their efforts still fell short of decisive success, Santos Dumont, having abandoned his airships, suddenly appeared in the field; in October 1906 he made an officially witnessed flight of 80 yds. in a biplane of his own design, the first heavier-than-air flight to be made from the soil of Europe. In the following year Henri Farman began to make short flights, and in 1908 Wilbur Wright arrived in France, and hearing that Orville in America had satisfied the tests imposed by the U.S.A. military authorities, on the 21st September flew for over an hour and a half, covering a distance of more than 60 miles. From this time progress was

rapid and continuous. In 1909 Blériot successfully flew across the English Channel, and in the same year the exploits of such men as Latham, Farman, and Curtis at the famous Rheims flying meeting roused enthusiasm and wonder throughout the civilized world.

In England, where the true theory of heavier-than-air flight had first been enunciated and the aeroplane had first taken definite shape, little was done in the early days of accomplished flight: although, thanks largely to the Aeronautical Society, interest never entirely ceased, and there is a line of continuity linking up Cayley, Stringfellow, and Pilcher with the exploits of F. S. Cody and A. V. Roe, the first British fliers.

Phillips made repeated though mostly unsuccessful experiments between 1893 and 1907, and by 1905 Cody had attracted official attention to his man-lifting kites. In 1908 he adapted one of these kites and fitted it with an engine and made a flight at Laffan's Plain, not far from the place where he met his death in 1913. Meanwhile Mr. A. V. Roe had constructed an aeroplane in 1907 and made gliding flights, but he could not obtain an engine until the following year, when he made his first flight at Brooklands, removing later to Lea Marshes. Other ardent pioneers were soon in the air, and after Blériot's cross-Channel flight, which made an enormous impression in England, flying became of regular occurrence, the encouragement given to aviation in these islands by Lord Northcliffe doing much to stimulate public interest and individual enterprise.

Dirigible airships had already been seen in Great Britain, Dr. Barton having navigated a dirigible balloon over London in 1900, and Mr. E. T. Willows designed a number of semi-rigid airships during the first decade of the twentieth century, in 1909 making a successful voyage from London to Cardiff at an average speed of about 14 miles an hour. The military authorities then turned their attention to the construction of airships, but in general Britain lagged considerably behind in the efficiency of her lighter-than-air craft until at least the later period of the Great War. It was the spur of military necessity that finally brought this country into

line with the great continental powers in the development of aircraft, both dirigible balloons and aeroplanes.

§ 2

Wilbur Wright died in 1912. He had lived to see the aeroplane recognized and accepted as a competent vehicle of flight throughout the civilized world. The improvements in the aero-engine, beginning with the introduction of the famous Gnome rotary engine, had given his invention a capacity for flight greater than he and his brother, in the days of their first success, had ever hoped to see. Yet he was not entirely satisfied. To the end he remained a true disciple of Lilienthal and felt that the glider was the essential factor in heavier-than-air flight. His imagination was continually haunted by recollections of the soaring birds that can maintain themselves in the air for such long periods without any expenditure of energy; it seemed to him that if only man could wrest this secret from the soaring birds it would be possible to construct a machine capable of sustained flight by virtue of its aerodynamic efficiency alone.

Whether this hope will ever be realized cannot as yet be hazarded, Nevertheless it is certain that the great increase in engine power placed at the disposal of the aeroplane had a marked effect upon its design and structure, and this influence was immeasurably augmented by the demands of the War. The energies of aeronautical science were for a long period chiefly directed to building aeroplanes capable of carrying these powerful engines and withstanding the increased strains and stresses that they entailed; and not to improving their intrinsic aerodynamic efficiency. It is a fact that the greater the motive power the easier it is to make any machine fly, providing its structure is sufficiently strong. It is only in recent years that the opposite tendency has been manifested in attempts to design aeroplanes capable of flight with a much reduced engine power. This healthy policy promises well, for such machines

must depend much more on their intrinsic airworthiness than do the large machines that are driven through the air by the sheer force of immense horse-power. Those in whose hands the future of the aeroplane as a flying vehicle rests will do wisely never to forget the beliefs and the methods of Lilienthal, Pilcher, and the Wrights.

Early, unhappily early, in their career aircraft were called upon to demonstrate their powers in warfare ; they have yet to prove fully their true value in times of peace. How far any mechanical contrivance can contribute to the ultimate happiness of mankind is a question one hesitates to answer ; so much depends on the uses to which it is put. Nevertheless it is safe to say that the aeroplane and the airship are new and powerful instruments of civilization ; they widen the scope of human activities and reduce the ever-present handicap imposed by time and space.

In an age of wonderful inventions and discoveries the conquest of the air was perhaps the most wonderful and inspiring of the material achievements of man. The story of this conquest, from its beginnings through failure to success, should offer us some consolation and encouragement. We live in times tinged with a certain shade of pessimism and doubt, when few are able to look into the future with complete assurance. Western civilization, it is not infrequently hinted, has passed its zenith and is fading to a decline. When one considers the activities of our own days, however, of which only one small manifestation has won for man the freedom of the air, it is difficult to acquiesce in this opinion. The characteristics that enabled the Western world to conquer the air—intellectual energy, imagination, faith, and dauntless courage—are not the characteristics of a decadent people.

INDEX